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RESEARCH MEMORANDUM

LIQUID-FUEL-DISTRIBUTION AND FUEL-STATE EFFECTS ON COMBUSTION PERFORMANCE OF A SINGLE TUBULAR COMBUSTOR

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

LIQUID-FUEL-DISTRIBUTION AND FUEL-STATE EFFECTS ON COMBUSTION PERFORMANCE OF A SINGLE TUBULAR COMBUSTOR

By Richard J. McCafferty

SUMMARY

An investigation was conducted to study the effects of liquid-fuel distribution on combustion performance of a single turbojet-engine combustor operating with liquid MIL-F-5624 fuel. The MIL-F-5624 fuel was injected with simplex and duplex pressure-atomizing nozzles and four solid-stream fuel distributors. Altitude operational limits and attendant combustion efficiencies and the effects of combustor inlet-air variables on combustion efficiency were determined. Gaseous-fuel-distribution data were available from a previous investigation for the same combustor and, hence, the effect of fuel state on performance was obtained by comparison.

Distribution of liquid fuel within the primary combustion zone of the combustor affects altitude operational limits and combustion efficiency, but to a lesser degree than does gaseous-fuel distribution. Gaseous fuel provided higher altitude operational limits and efficiencies than liquid fuel.

INTRODUCTION

Research is being conducted at the NACA Lewis laboratory to obtain information on the relative importance of various factors affecting the altitude performance of combustors for aircraft turbine engines. Part of this research is intended to provide information on the combustion characteristics of liquid and vapor hydrocarbon fuels and particularly to show whether vapor fuels have inherently better characteristics than liquid fuels when injected into a combustor operating at altitudes where the inlet-air conditions are adverse to combustion.

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Previous reports (references 1 and 2) show that liquid-fuel combustion is detrimentally affected by increasing altitude. This altitude effect is, in part, attributed to the lack of rapid attainment of proper fuel-air mixtures in the primary combustion zone at high-altitude conditions. In these combustors, the fuel was injected by pressure-atomizing nozzles and vaporization occurred from the surface of the liquid-fuel droplets so formed. In this manner the liquid fuel was distributed, vaporized, and mixed with air before combustion occurred. Quenching by dilution air limited the residence time available for complete combustion. 2123

Vapor fuel should provide a combustible fuel-air mixture in the primary combustion zone more rapidly than liquid fuel because the time requirement of vaporization is eliminated. Consequently, the combustion performance of vapor fuel should be superior because the fuel enjoys a longer residence time in the combustion zone while in the vapor state.

In order to draw any conclusions regarding the importance of fuel state, the effect of fuel distribution with both liquid and vapor fuels must first be appraised. A previous report (reference 3) presents the results of an investigation concerning the effect of fuel-air distribution on combustion characteristics with vapor fuel. The present report presents data showing the effect of liquid fuel distribution on combustion performance. The data were obtained by operation of a single tubular combustor with liquid MIL-F-5624 fuel, and variation in fuel distribution in the combustion zone was accomplished by the use of six fuel-injector designs. The combustion characteristics were evaluated by (1) determining the altitude operational limits and attendant combustion efficiencies, and (2) determining the effects of inlet-air pressure, temperature, and velocity on combustion efficiency at standard inlet-air conditions of 620° R and 15 pounds per square inch absolute. The liquid-fuel performance so determined is compared with the previously reported gaseous-fuel performance. Observations regarding the carbon-forming tendencies, stability, and ignition characteristics are also included.

APPARATUS AND INSTRUMENTATION

Equipment

The investigations were conducted in a single combustor from a J35-C-3 turbojet engine. The combustor was connected to the laboratory air supply, as shown diagrammatically in figure 1; air quantity and pressure were regulated by remote-control valves upstream and downstream of the combustor. The desired inlet-air temperature was obtained by burning a portion of the air with gasoline in a preheater and then mixing it uniformly with the rest of the air upstream of the combustor. 2123 The effect on the constituents of the inlet air due to the added products of combustion is discussed in reference 1. The exhaust gases were cooled by water sprays in the exhaust ducting.

The combustor-inlet section and the combustor itself were furnished by the manufacturer. The inlet and outlet ducts were fabricated to simulate the dimensions and contours of corresponding engine ducts. The combustor outer wall was reinforced with metal bands to eliminate structural failure at the low interior pressures investigated. Observation windows were located axially along the combustor to permit visual observation of combustion.

Instrumentation

The number of instruments at each of the instrumentation planes shown in figure 1 are as follows:

Type of instrument	Instrumentation plane			
	2	3	4	5
One-thermocouple rake	2			3
Three-tube total-pressure rake	3			
Five-thermocouple rake		7		
Five-tube total-pressure rake			7	
Static-pressure orifice	1	1	1	

All temperature and total-pressure measurements were taken at the centers of equal areas. Instrumentation plane 2 is located at the combustor inlet, which has a cross-sectional area of 0.159 square foot; instrumentation plane 3 is at the combustor outlet, where the cross-sectional area is 0.262 square foot. Locations of the points of measurement at the respective instrumentation planes are shown in figure 2, and the instrumentation details are shown in figure 3. Air-flow rate was metered by a square-edge orifice installed according to A.S.M.E. specifications; temperatures were indicated by self-balancing potentiometers; and liquid-fuel flow rate was indicated by a calibrated rotameter.

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Fuel and Fuel Injectors

The MIL-F-5624 fuel used in this investigation had the following characteristics as determined by standard A.S.T.M. methods:

Boiling range (°F)	Reid vapor pressure (lb/sq in.)	Specific gravity 60°/60° F	Hydrogen-carbon ratio	Net heating value (Btu/lb)	Aromatics (percent by volume)	Olefins (percent by volume)
106-556	7	0.738	0.179	18,900	10	2.5

The fuel was injected through various fuel-injector devices after passing through a 200-mesh filter screen that removed foreign matter. The duplex-type pressure-atomizing nozzle and flow-divider apparatus are standard for the J35-C-3 engine. The different injectors that were installed in the combustor in the same relative position as the duplex nozzle are:

Simplex injector. - The standard duplex-type nozzle was modified by removing the internal parts and replacing the end of the nozzle housing with a 1/2-inch-diameter standard pipe coupling machined to the same outer diameter as the nozzle, and the simplex-type nozzle was attached with a suitable reducer. The simplex-type nozzle was a constant-area single-orifice pressure-atomizing nozzle having a 21.5-gallon-per-hour capacity, rated at 100 pounds per square inch pressure differential, and a 60°-angle hollow-cone spray.

"Spoke" injector. - A 1/2-inch pipe nipple was attached to the modified-duplex housing already described, and eight 1/4-inch-diameter tubes were arranged as radial spokes on the nipple. Five 0.0135-inch-diameter holes were drilled in each tube to inject fuel at centers of equal areas. A diagrammatic sketch of this injector is shown in figure 4(a).

Tube "A" injector. - A stainless-steel 3/4-inch-diameter tube was drilled with forty 0.0135-inch-diameter holes to provide the same total port area as the "spoke" injector, and the holes were evenly spaced circumferentially at predetermined lengths from the upstream end of the tube to maintain the same proportion of total fuel-port area to total primary-zone-hole area. The primary-zone-hole area was considered to be the upstream one-fourth of the total hole area of the liner. In this manner the fuel-port area was matched with the air-hole area in an attempt to provide approximately stoichiometric fuel-air mixtures along the combustion zone. The exact fuel-air proportions at any given place in the combustion zone were not calculable because the discharge coefficients of the air and fuel ports were not accurately known, because the amount of air carried upstream by the backflow eddies from the dilution to the primary combustion zone was not known, and because the fuel diffusion rates were not known. A diagrammatic sketch of this injector is shown in figure 4(b).

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Tube "B" injector. - The tube "B" injector was geometrically similar to the tube "A" injector, but the linear hole distribution pattern was reversed by turning end-for-end the injector tube, as shown in figure 4(c). The fuel distribution produced by this injector tube was exactly opposite that of tube "A" with reference to linear distance along the combustion zone.

Tube "C" injector. - The stainless-steel 3/4-inch-diameter tube was drilled with forty 0.0135-inch-diameter holes evenly spaced along the length of the tube to provide a linear fuel distribution along the combustion zone. A diagrammatic sketch of this injector is shown in figure 4(d).

PROCEDURE

The combustion performance was studied by (1) determining altitude operational limits and combustion efficiencies at various simulated-flight conditions, and (2) determining the influence of combustor-inlet air-pressure, temperature, and velocity on combustion efficiency and temperature rise at the standard inlet-air conditions of 620° R and 15 pounds per square inch absolute. These determinations were made with liquid MIL-F-5624 fuel and with the following fuel-injection devices: standard duplex-type nozzle, simplex-type nozzle, "spoke" injector, tube "A" injector, tube "B" injector, and tube "C" injector.

Estimated combustor inlet-air conditions and combustor outlet-gas temperatures corresponding to zero-ram operation of the engine at various altitudes and rotor speeds were obtained from the engine manufacturer and are shown in figure 5. These performance curves were used to establish the combustor operating conditions necessary to simulate engine operation at any desired altitude and rotor speed. Details of the operational methods and data-recording procedures are described in reference 2.

With the use of charts given in reference 4, the combustion efficiency was computed as the ratio of the measured enthalpy rise across the combustor to the heating value of the fuel. Air reference velocity values were computed from the maximum cross-sectional area of the combustor flow passage (0.48 square foot), the inlet-air density, and the total air-flow rate. The thermocouple indications were taken as true values of total temperatures with no corrections made for stagnation or radiation effects.

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RESULTS AND DISCUSSION

Altitude Limits and Combustion Efficiencies

The data obtained with the various liquid-fuel injection devices are summarized in table I. The test runs labeled "no combustion" are those in which repeated attempts produced no burning at any fuel flow. Altitude operational limits of the single tubular combustor are presented in figure 6 for each fuel injector investigated. Each curve separates the region where sufficient combustor-outlet temperatures are attainable from the region where the maximum attainable outlet temperatures are insufficient for nonaccelerating operation of the engine. A comparison of the altitude operational limits obtained is shown in figure 7. Variation of combustion efficiency with inlet-air pressure, temperature, and reference velocity is shown in figures 8, 9, and 10, respectively. The original data (table I) were taken at a series of fuel-air ratios for each inlet-parameter value studied, and the curves of figures 8 to 10 were cross-plotted at 650° and 1200° F combustor temperature rise from those data.

Liquid-Fuel Distribution

The following discussions are based on performance comparisons obtained at conditions where the combustor-inlet values are such that any performance differences that do exist are of sufficient magnitude to be significant.

There exists a difference, other than fuel distribution, between the pressure-atomizing nozzles and the solid-stream fuel injectors studied. The pressure-atomizing nozzles produced smaller fuel drops than those that resulted from the disintegration of a solid fuel stream as it mixed with the primary air. These smaller drops gave higher rates of vaporization, and thus allowed more time for mixing and combustion. For this reason these two types of fuel injection will be considered separately.

Pressure-atomizing nozzles. - The two pressure-atomizing nozzles gave approximately the same altitude operational limits (fig. 7), and their combustion efficiency performances showed no consistent differences (figs. 8, 9, and 10). Inasmuch as the two nozzles differ in fuel-spray characteristics, with the duplex providing atomization over a larger range of fuel flows than the simplex, the lack of consistent combustion-efficiency values is understandable.

2123 Solid-stream injectors. - The altitude operational limits (fig. 7) of the tube "A" injector were 5000 to 8500 feet higher than those of the best of the other three solid-stream injectors except at the highest simulated rotor speeds. Tube "B" gave operating limits nearly identical to those for tube "A" at rotor speeds above 80-percent rated. The "spoke" injector, although quite inferior at intermediate simulated rotor speeds, gave limits 5000 feet above those for tube "A" at 104 percent normal rated speed. Variation in liquid fuel distribution as provided by the fuel injectors studied does affect altitude operational limits, but the effect becomes small at the highest engine rotor speeds where the engine normally operates. A possible explanation of this rotor-speed effect is that the inlet-air temperature and the temperature-rise requirement have a wide range of values throughout the engine rotor speeds investigated. The high inlet-air temperatures encountered at the high rotor-speed conditions vaporize the liquid fuel more rapidly and may thus diminish the effect of liquid-fuel distribution on altitude operational limits. Similarly, the high temperature-rise requirement demands a larger fuel flow rate, which may decrease the differences in fuel-injection characteristics of the several injection devices.

The combustion efficiencies (figs. 8, 9, and 10) of tube "A" were generally above those of the other stream injectors at the 1200° F temperature-rise condition. At the 650° F temperature-rise condition, however, tube "B" was generally best and gave efficiencies at times 8 percent above those for tube "A". Comparison of the altitude operational limits and combustion-efficiency performance of the four stream injectors studied shows that tube "A" provided the best over-all performance. This result indicates that the optimum fuel distribution is one which proportions the fuel with the incoming air to give approximately stoichiometric mixtures. This conclusion is not strongly borne out by the data, because tube "B" gave better efficiency than tube "A" at some operating conditions and because the differences in performance of the better injectors were not great at most conditions of operation.

The "spoke" injector provided the lowest combustion efficiencies of all the injection devices studied. The poor performance shown by this injector is believed to be due to overrich fuel-air ratios existing in the immediate upstream end of the primary zone. As a result, the proper fuel-air mixture is not obtained rapidly enough in the primary zone to allow the establishment of a stable flame in the upstream end of the combustor.

Fuel State

Altitude operational limits of the single tubular combustor are presented in figure 11 for both liquid and gaseous fuels. The gaseous-fuel data are taken from reference 3. These curves represent the best and the poorest performance limits obtainable with both liquid and gaseous fuels for all the solid-stream fuel patterns studied. Combustion efficiencies obtained with both liquid and gaseous fuels operating with the same fuel injectors as for figure 11 at various inlet-air pressures, temperatures, and velocity values are shown in figures 12, 13, and 14. 2123

The highest limits, by 6000 to 10,000 feet, were obtained with gaseous-propane fuel and a tube injector. The lowest limits were obtained also with gaseous fuel and a single-port injector. The wide dispersion of limit curves obtained with gaseous fuel shows that fuel distribution has a greater effect on operational-limit performance with gaseous fuel than with liquid fuel.

The combustion-efficiency performance with both fuels (figs. 11, 12, and 13) shows that the gaseous-fuel injection (tube and single port) provided higher efficiencies than the liquid-fuel injectors at most of the conditions investigated. This result indicates that the finite time required for fuel vaporization, which would reduce the time available for combustion, has a measurable effect on combustion performance.

From the data presented herein,the conclusion may be reached that vapor fuel, properly supplied to a combustion chamber, will give higher efficiencies and higher altitude operational limits than liquid fuel; this conclusion must be regarded as tentative because only a limited number of fuels and fuel-injection devices have been investigated. Further, this study has not included the problem of vaporizing liquid fuel for a vapor-fed combustor.

Miscellaneous Observations

The tube "B" and tube "C" fuel distributions produced rather violent combustion pulsations at all fuel-air ratios, and blow-out frequently occurred even while operating at high combustion efficiency. Special spark-plug electrode designs were necessary to initiate combustion with the fuel distribution produced by the solid-stream injectors. The electrodes of these plugs were extended 3 to 4 inches and bent to place the electrode gap in a fuel-rich part of the primary zone. No appreciable carbon deposits were formed in the combustion chamber, except that a noticeable scale-like film having a tendency to flake was formed on the tube injectors.

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SUMMARY OF RESULTS

The results obtained in the investigation of the effect of liquid fuel distribution and fuel state on combustion performance in a single tubular combustor from a 4000-pound-thrust turbojet engine are summarized as follows:

1. Distribution of liquid fuel within the primary zone of the combustor affected performance with relation to altitude operational limits, but the effect became small at the highest engine rotor speeds. Fuel distribution had a greater effect on performance with gaseous fuel than with liquid fuel.

2. Of the solid-stream injectors investigated, the best over-all performance was obtained with the tube injector that admitted the fuel through holes matched with the distribution of primary air holes in the combustor liner so as to provide approximately stoichiometric proportioning of fuel and air along the length of the combustor.

CONCLUDING REMARKS

Vapor fuel properly supplied to the combustor gave higher efficiencies and altitude operational limits than liquid fuel for the types of fuel and fuel distribution investigated. This indicates that the process of fuel vaporization is an important combustor function influencing combustion performance at high altitudes. It should be pointed out that a limited number of fuel-distribution patterns were investigated and, further, that methods of providing for prevaporization of liquid fuel were not studied. Future development of fuel-injection technique may provide better combustion performance with liquid fuels.

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REFERENCES

1. Childs, J. Howard, McCafferty, Richard J., and Surine, Oakley W.: Effect of Combustor-Inlet Conditions on Performance of an Annular Turbojet Combustor. NACA Rep. 881, 1947. (Formerly NACA TN 1357.) 2123

2. McCafferty, Richard J.: Effect of Fuels and Fuel-Nozzle Characteristics on Performance of an Annular Combustor at Simulated Altitude Conditions. NACA RM E8C02a, 1948.

3. McCafferty, Richard J.: Vapor-Fuel-Distribution Effects on Combustion Performance of a Single Tubular Combustor. NACA RM E50J03, 1950.

4. Turner, L. Richard, and Bogart, Donald: Constant-Pressure Combustion Chart Including Effects of Diluent Addition. NACA Rep. 937, 1949. (Formerly NACA TNs 1086 and 1655.)

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TABLE I - PERFORMANCE DATA FROM COMBUSTOR OPERATING WITH LIQUID MIL-F-5624 FUEL INJECTED BY SEVERAL DIFFERENT METHODS

(a) Duplex injector

Point	Simulated engine speed (rpm)	Simulated altitude (ft)	Combustor-inlet static pressure (in. Hg)	Combustor-inlet temperature, °R	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet temperature, °R	Mean temperature rise through combustor (°F)	Combustion efficiency
Altitude operational limits											
1	8000	50,000	18	680	1.34	79.3	96	0.0199	1880	1200	0.867
1	8000	50,000	18	680	1.34	79.3	117	.0243	2100	1420	.862
2	8000	60,000	11	710	.86	87.0	70	.0226	1880	1170	.752
3	8000	65,000	8	710	.65	90.4	No combustion				
6	7000	60,000	9	660	.77	88.6	55	.0198	1580	920	.654
6	7000	60,000	9	660	.77	88.6	64	.0231	1640	980	.606
7	7000	65,000	6	660	.55	94.8	No combustion				
10	6000	60,000	7	590	.65	85.9	34	.0146	1275	685	.639
11	6000	65,000	5	590	.50	92.4	No combustion				
24	3000	40,000	7	440	.60	59.2	34	.0158	1090	650	.550
24	3000	40,000	7	440	.60	59.2	36	.0167	1100	660	.528
25	3000	50,000	5	440	.34	46.9	No combustion				
20	4000	50,000	6	480	.56	70.2	32	.0159	1040	560	.470
18	4000	40,000	10	480	.89	67.0	42	.0131	1040	560	.566
14	5000	50,000	8	520	.80	81.6	48	.0167	1080	560	.450
16	5000	60,000	5	520	.50	81.5	No combustion				
15	5000	55,000	7	530	.65	77.2	39	.0167	1010	480	.385
15	5000	55,000	7	530	.65	77.2	44	.0188	1080	550	.394
		Point	Combustion efficiencies - reference condition								
		661	30.5	620	2.60	82.8	51	0.0054	1030	410	0.990
		662	30.5	620	2.60	82.8	83	.0088	1230	610	.921
		663	30.5	620	2.60	82.8	109	.0116	1405	785	.917
		664	30.5	620	2.60	82.8	144	.0154	1660	.1040	.943
		665	30.5	620	2,60	82.8	171	.0183	1840	1220	.948
		666	30.5	620	2.60	82.8	203	.0217	2045	1425	.953
		Combustion efficiencies - effect of pressure									
		676	16.9	620	1.45	83.3	55	0.0066	1080	460	0.927
		677	16.9	620	1.45	83.3	56	.0107	1340	720	.909
		678	16.9	620	1.45	83.3	79	.0151	1560	940	.862
		679	16.9	620	1.45	83.3	100	.0192	1790	1170	.867
		680	16.9	620	1.45	83.3	124	.0238	2020	1400	.858
		Combustion efficiencies - effect of temperature									
		690	30.5	430	3.72	82.6	53	0.0040	675	245	0.796
		691	30.5	430	3.72	82.6	98	.0073	835	405	.719
		692	30.5	430	3.72	82.6	144	.0108	1040	610	.747
		693	30.5	430	3.72	82.6	192	.0143	1240	810	.756
		694	30.5	430	3.72	82.6	217	.0162	1360	930	.779
		695	30.5	430	3.72	82.6	243	.0181	1475	1045	.789
		696	30.5	430	3.72	82.6	272	.0203	1580	1150	.785
		Combustion efficiencies - effect of velocity									
		667	30.5	620	4.20	134	90	0.0060	1030	410	0.907
		668	30.5	620	4.20	134	146	.0096	1215	595	.828
		669	30.5	620	4.20	134	207	.0137	1410	790	.791
		670	30.5	620	4.20	134	274	.0181	1625	1005	.778
		671	30.5	620	4.20	134	345	.0228	1840	1220	.769
		672	30.5	620	1.00	31.8	35	.0097	1350	730	.985
		673	30.5	620	1.00	31.8	46	.0128	1570	950	1.02
		674	30.5	620	1.00	31.8	62	.0172	1800	1180	.970
		675	30.5	620	1.00	31.8	77	.0214	2010	1390	.940

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TABLE I - PERFORMANCE DATA FROM COMBUSTOR OPERATING WITH LIQUID MIL-F-5624 FUEL INJECTED BY SEVERAL DIFFERENT METHODS - Continued

(b) Simplex injector

Point	Simulated engine speed (rpm)	Simulated altitude (ft)	Combustor inlet static pressure (in. Hg)	Combustor-inlet tempera-ture, °R	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet tempera-ture, °R	Mean tem-perature rise through combustor (°F)	Combustion efficiency	Total-pressure drop through combustor (in. Hg)	Fuel-nozzle pressure differential (in. Hg)
		Altitude operational limits											
1	8000	50,000	18	710	1.34	82.8	92	0.0191	1885	1175	0.885	1.1	96
2	8000	60,000	11	710	.85	86.0	77	.0252	1880	1170	.878	1.1	67
3	8000	65,000	8	710	.65	90.4	55	.0235	1810	1100	.677	1.0	41
6	7000	60,000	9	655	.78	89.0	55	.0196	1585	930	.868	.7	40
7	7000	65,000	6	655	.55	94.1	No combustion						
4	7000	50,000	15	655	1.22	83.5	74	.0168	1580	925	.767	---	63
10	6000	60,000	7	590	.65	85.9	41	.0175	1275	685	.534	.5	--
11	6000	65,000	5	590	.50	92.4	No combustion						
8	6000	50,000	12	590	1.05	80.9	54	.0143	1260	670	.634	.7	45
24	3000	40,000	7	460	.60	61.8	29	.0134	1085	625	.615	.4	--
24	3000	40,000	7	46C	.80	61.8	41	.0190	1220	760	.540	---	--
25	3000	50,000	5	460	.34	49.1	No combustion						
20	4000	50,000	6	460	.56	67.3	38	.0188	1040	580	.410	---	--
20	4000	50,000	6	460	.56	67.3	44	.0218	1135	675	.418	.4	--
18	4000	40,000	10	460	.89	64.2	43	.0134	1045	585	.576	.4	--
14	5000	50,000	8	530	.80	83.2	43	.0149	1110	580	.520	.5	--
14	5000	50,000	8	530	.80	83.2	40	.0139	1080	550	.527	.5	--
16	5000	60,000	5	530	.50	83.0	No combustion						
15	5000	55,000	7	530	.65	77.2	32	.0137	1040	510	.495	.4	--
15	5000	55,000	7	530	.65	77.2	37	.0158	1080	550	.465	.4	--
Point			Combustion efficiencies - reference condition										
587			30.5	620	2.60	82.8	58	0.0062	980	360	0.762	1.0	40
588			30.5	620	2.60	82.8	79	.0084	1160	540	.853	1.1	70
589			30.5	620	2.60	82.8	103	.0110	1360	740	.911	1.3	117
590			30.5	620	2.60	82.8	138	.0148	1625	1005	.948	1.7	202
591			30.5	620	2.60	82.8	159	.0170	1780	1160	.982	---	---
			Combustion efficiencies - effect of pressure										
630			44.4	620	3.78	82.8	73	0.0064	945	325	0.878	---	63
631			44.4	620	3.78	82.8	110	.0080	1160	540	.888	---	135
632			44.4	620	3.78	82.8	146	.0107	1355	735	.928	---	---
633			44.4	620	3.78	82.8	189	.0139	1560	940	.935	---	---
634			44.4	620	3.78	82.8	227	.0167	1760	1140	.961	---	---
624			16.9	620	1.44	82.8	41	.0079	1010	390	.650	---	20
625			16.9	620	1.44	82.8	53	.0102	1170	550	.720	---	36
626			16.9	620	1.44	82.8	73	.0141	1425	805	.784	---	61
627			16.9	620	1.44	82.8	88	.0170	1655	1035	.853	---	89
628			16.9	620	1.44	82.8	103	.0199	1860	1240	.890	---	117
629			16.9	620	1.44	82.8	123	.0237	2070	1450	.890	---	166
			Combustion efficiencies - effect of temperature										
635			30.5	805	2.00	82.7	47	0.0065	1160	355	0.734	---	36
636			30.5	805	2.00	82.7	63	.0087	1340	535	.837	---	54
637			30.5	805	2.00	82.7	85	.0118	1555	750	.888	---	84
638			30.5	805	2.00	82.7	108	.0150	1760	955	.907	---	132
639			30.5	805	2.00	82.7	148	.0206	2090	1285	.920	---	---
640			30.5	435	3.70	82.6	89	.0066	855	420	.812	---	97
641			30.5	435	3.70	82.6	130	.0098	1070	635	.854	---	200
642			30.5	435	3.70	82.6	164	.0123	1240	805	.870	---	---
643			30.5	435	3.70	82.6	198	.0149	1435	1000	.911	---	---
644			30.5	435	3.70	82.6	216	.0162	1510	1075	.905	---	---
			Combustion efficiencies - effect of velocity										
652			30.5	620	4.20	134	114	0.0075	1075	455	0.798	---	---
653			30.5	620	4.20	134	163	.0108	1275	655	.819	---	---
654			30.5	620	4.20	134	205	.0136	1425	805	.812	---	---
655			30.5	620	4.20	134	256	.0169	1530	910	.746	---	---
612			30.5	620	1.00	82.8	29	.0080	1110	490	.808	---	16
613			30.5	620	1.00	82.8	40	.0111	1310	690	.840	---	---
614			30.5	620	1.00	82.8	49	.0136	1520	900	.911	---	32
615			30.5	620	1.00	82.8	62	.0172	1750	1130	.924	---	---
616			30.5	620	1.00	82.8	75	.0208	1960	1340	.925	---	64
617			30.5	620	1.00	82.8	87	.0242	2170	1550	.940	---	90

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TABLE I - PERFORMANCE DATA FROM COMBUSTOR OPERATING WITH LIQUID MIL-F-5624 FUEL INJECTED BY SEVERAL DIFFERENT METHODS - Continued

(c) Tube "A" injector

Point	Simulated engine speed (rpm)	Simulated altitude (ft)	Combustor inlet static pressure (in. Hg)	Combustor inlet temperature, °R	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor outlet temperature, °R	Mean temperature rise through combustor (°F)	Combustion efficiency
Altitude operational limits											
1	8000	50,000	18	695	1.34	81.0	91	0.0189	1880	1185	0.902
1	8000	50,000	18	695	1.34	81.0	118	.0245	2160	1465	.885
2	8000	60,000	11	720	.86	88.2	67	.0216	1860	1140	.768
6	7000	60,000	9	655	.77	87.9	58	.0202	1600	945	.861
7	7000	65,000	6	660	.55	94.8	44	.0222	1285	625	.392
7	7000	65,000	6	660	.55	94.8	43	.0217	1230	570	.365
10	6000	60,000	7	600	.65	87.4	38	.0162	1280	660	.554
10	6000	60,000	7	595	.65	86.6	43	.0184	1335	740	.554
11	6000	65,000	5	580	.50	90.9	42	.0233	985	405	.237
24	3000	40,000	7	460	.60	59.2	32	.0148	1110	650	.584
25	3000	50,000	5	460	.34	49.1		No combustion			
18	4000	40,000	10	490	.89	68.4	37	.0116	1260	770	.892
18	4000	40,000	10	460	.89	64.2	34	.0106	1110	650	.809
20	4000	50,000	6	480	.56	70.2	38	.0188	1160	680	.486
20	4000	50,000	6	480	.56	70.2	34	.0169	1060	580	.459
21	4000	60,000	4	480	.34	64.0		No combustion			
16	5000	60,000	5	525	.50	82.2	34	.0189	910	385	.272
15	5000	55,000	7	525	.65	76.4	34	.0145	1110	585	.538
Combustion efficiencies - reference condition											
724			30.5	620	2.60	82.8	61	0.0065	1030	410	0.830
725			30.5	620	2.60	82.8	96	.0102	1310	690	.910
726			30.5	620	2.60	82.8	124	.0132	1490	870	.902
727			30.5	620	2.60	82.8	160	.0171	1740	1120	.924
728			30.5	620	2.60	82.8	203	.0217	2040	1420	.950
729			30.5	620	2.60	82.8	220	.0235	2160	1540	.961
730			30.5	620	2.60	82.8	175	.0187	1880	1260	.962
Combustion efficiencies - effect of pressure											
737			44.4	620	3.78	82.8	87	0.0064	1070	450	0.929
738			44.4	620	3.78	82.8	120	.0088	1250	630	.959
739			44.4	620	3.78	82.8	170	.0125	1490	870	.955
740			44.4	620	3.78	82.8	208	.0153	1680	1060	.968
741			44.4	620	3.78	82.8	249	.0183	1880	1260	.981
742			44.4	620	3.78	82.8	298	.0219	2110	1490	.991
710			16.9	620	1.44	82.8	34	.0068	1080	460	.927
711			16.9	620	1.44	82.8	54	.0104	1270	650	.841
712			16.9	620	1.44	82.8	77	.0148	1510	890	.828
713			16.9	620	1.44	82.8	97	.0187	1810	1190	.904
714			16.9	620	1.44	82.8	120	.0232	2035	1415	.889
Combustion efficiencies - effect of temperature											
743			30.5	810	2.00	83.2	54	0.0075	1285	475	0,863
744			30.5	810	2.00	83.2	75	.0104	1450	640	.853
745			30.5	810	2.00	83.2	102	.0142	1710	900	.902
746			30.5	810	2.00	83.2	125	.0174	1920	1110	.926
747			30.5	810	2.00	83.2	159	.0221	2185	1375	.928
748			30.5	435	3.70	82.6	88	.0066	820	385	.754
749			30.5	435	3.70	82.6	139	.0104	1020	585	.736
750			30.5	430	3.70	81.7	189	.0142	1220	790	.744
751			30.5	430	3.70	81.7	244	.0183	1510	1080	.809
752			30.5	430	3.70	81.7	286	.0215	1710	1230	.835
753			30.5	430	3.70	81.7	337	.0253	1960	1530	.868
Combustion efficiencies - effect of velocity											
731			30.5	620	4.20	134	95	0.0062	1035	415	0.872
732			30.5	620	4.20	134	154	.0102	1260	640	.846
733			30.5	620	4.20	134	203	.0134	1430	810	.827
734			30.5	620	4.20	134	247	.0163	1590	970	.828
735			30.5	620	4.20	134	290	.0192	1750	1130	.834
736			30.5	620	4.20	134	339	.0224	1960	1340	.864
707			30.5	620	1.00	31.8	54	.0150	1635	1015	.942
708			30.5	620	1.00	31.8	71	.0197	1865	1265	.916
709			30.5	620	1.00	31.8	82	.0228	2060	1440	.922

TABLE I - PERFORMANCE DATA FROM COMBUSTOR OPERATING WITH LIQUID MIL-F-5624 FUEL INJECTED BY SEVERAL DIFFERENT METHODS - Continued

(d) "Spoke" injector

Point	Simulated engine speed (rpm)	Simulated altitude (ft)	Combustor inlet static pressure (in. Hg)	Combustor inlet temperature, °R	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor outlet temperature, °R	Mean temperature rise through combustor (°F)	Combustion efficiency
Altitude operational limits											
24	3000	40,000	7	440	0.80	59.2	34	0.0158	930	490	0.409
23	3000	30,000	12	440	.89	51.1	67	.0209	1035	595	.381
23	3000	30,000	12	440	.89	51.1	88	.0275	1160	720	.358
18	4000	40,000	10	480	.89	67.0	54	.0169	1070	590	.467
18	4000	40,000	10	480	.89	67.0	50	.0156	1080	600	.512
20	4000	50,000	6	480	.56	70.2	35	.0174	960	480	.367
19	4000	45,000	8	480	.72	66.8	45	.0174	1040	560	.430
14	5000	50,000	8	530	.80	83.2	42	.0146	990	460	.419
14	5000	50,000	8	530	.80	83.2	44	.0153	1040	510	.446
16	5000	60,000	5	530	.50	83.0	No combustion				
12	6000	40,000	14	520	1.27	74.0	79	.0173	1080	560	.435
10	6000	60,000	7	590	.65	85.9	No combustion				
8	6000	50,000	12	590	1.05	80.9	62	.0164	1320	730	.608
8	6000	50,000	12	590	1.05	80.9	53	.0140	1285	695	.664
6	7000	60,000	9	660	.77	88.6	44	.0159	1335	675	.586
4	7000	50,000	15	650	1.22	82.8	92	.0209	1580	930	.628
5	7000	55,000	12	650	1.00	84.9	79	.0219	1580	930	.600
2	8000	60,000	11	710	.86	87.0	83	.0268	1985	1275	.703
2	8000	60,000	11	710	.86	87.0	78	.0246	1880	1170	.696
3	8000	65,000	8	710	.65	90.4	No combustion				
Point	Combustion efficiencies - reference condition										
792			30.5	620	2.60	82.8	123	0.0132	860	240	0.243
793			30.5	620	2.60	82.8	176	.0188	1160	540	.393
794			30.5	620	2.60	82.8	214	.0229	1650	1030	.640
795			30.5	620	2.60	82.8	248	.0265	1970	1350	.744
Combustion efficiencies - effect of pressure											
801			44.4	620	3.78	82.8	140	0.0103	1085	465	0.603
802			44.4	620	3.78	82.8	175	.0128	1285	665	.702
803			44.4	620	3.78	82.8	213	.0156	1490	870	.769
804			44.4	620	3.78	82.8	251	.0184	1690	1070	.818
805			44.4	620	3.78	82.8	296	.0217	1945	1325	.879
786			16.9	620	1.44	82.8	43	.0083	1035	415	.662
787			16.9	620	1.44	82.8	78	.0150	1110	490	.441
788			16.9	620	1.44	82.8	106	.0205	1240	620	.418
789			16.9	620	1.44	82.8	138	.0266	1440	820	.436
790			16.9	620	1.44	82.8	174	.0336	1730	1110	.484
791			16.9	620	1.44	82.8	207	.0400	1910	1290	.486
Combustion efficiencies - effect of temperature											
806			30.5	805	2.00	82.7	76	0.0105	1335	530	0.694
807			30.5	805	2.00	82.7	118	.0164	1560	755	.654
808			30.5	805	2.00	82.7	159	.0221	1810	1005	.665
809			30.5	805	2.00	82.7	203	.0282	2190	1385	.744
754			30.5	440	3.70	83.6	118	.0088	810	370	.542
755			30.5	440	3.70	83.6	154	.0116	1010	570	.648
756			30.5	440	3.70	83.6	188	.0141	1200	760	.720
757			30.5	435	3.70	82.6	227	.0170	1410	975	.778
758			30.5	435	3.70	82.6	269	.0202	1595	1160	.801
759			30.5	435	3.70	82.6	298	.0224	1760	1325	.833
760			30.5	430	3.70	81.7	332	.0249	1830	1400	.798
Combustion efficiencies - effect of velocity											
796			30.5	620	4.20	134	159	0.0105	1135	515	0.656
797			30.5	620	4.20	134	198	.0131	1290	670	.695
798			30.5	620	4.20	134	229	.0151	1430	810	.736
799			30.5	620	4.20	134	268	.0177	1620	1000	.791
800			30.5	620	4.20	134	300	.0198	1770	1150	.824
781			30.5	620	1.00	82.8	35	.0097	1250	630	.872
782			30.5	620	1.00	82.8	56	.0156	1320	700	.616
783			30.5	620	1.00	82.8	80	.0222	1510	890	.563
784			30.5	620	1.00	82.8	100	.0278	2085	1465	.778
785			30.5	620	1.00	82.8	86	.0239	1760	1140	.684

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TABLE I - PERFORMANCE DATA FROM COMBUSTOR OPERATING WITH LIQUID MIL-F-5624 FUEL INJECTED BY SEVERAL DIFFERENT METHODS - Continued

(e) Tube "B" injector

Point	Simulated engine speed (rpm)	Simulated altitude (ft)	Combustor inlet static pressure (in. Hg)	Combustor-inlet tempera-ture, °R	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor outlet tempera-ture, °R	Mean tem-perature rise through combustor (°F)	Combustion efficiency
Altitude operational limits											
24	3000	40,000	7	440	0.60	58.2	No combustion				
22	3000	20,000	18	450	1.24	----	55	0.0123	1220	770	0.832
23	3000	30,000	12	460	.90	54.0	41	.0126	1120	660	.751
18	4000	40,000	10	450	.89	62.8	34	.0106	1040	590	.731
20	4000	50,000	6	450	.56	65.9	No combustion				
14	5000	50,000	8	525	.80	82.4	No combustion				
13	5000	45,000	11	525	1.00	----	34	.0094	1080	555	.776
2	8000	60,000	11	720	.86	88.2	54	.0174	1660	940	.762
2	8000	60,000	11	720	.86	88.2	60	.0194	1810	1030	.807
1	8000	50,000	18	700	1.34	81.6	93	.0193	1880	1180	.880
6	7000	60,000	9	655	.77	87.9	55	.0198	1580	925	.857
7	7000	65,000	6	655	.55	94.1	No combustion				
10	6000	60,000	7	600	.65	87.4	38	.0162	1240	640	.536
10	6000	60,000	7	600	.65	87.4	44	.0188	1280	680	.504
11	6000	65,000	5	590	.50	92.4	No combustion				
Point			Combustion efficiencies - reference condition								
852			30.5	620	2.60	82.8	67	0.0072	1135	515	0.956
853			30.5	620	2.60	82.8	95	.0102	1310	690	.916
854			30.5	620	2.60	82.8	124	.0132	1460	840	.870
855			30.5	620	2.60	82.8	159	.0170	1735	1115	.923
856			30.5	620	2.60	82.8	183	.0196	1910	1230	.944
857			30.5	620	2.60	82.8	207	.0221	2060	1440	.946
Combustion efficiencies - effect of pressure											
865			44.4	620	3.80	83.2	62	0.0045	960	340	0.980
867			44.4	620	3.80	83.2	142	.0104	1360	740	.965
868			44.4	620	3.80	83.2	175	.0128	1535	915	.986
869			44.4	620	3.80	83.2	215	.0157	1710	1090	.972
870			44.4	620	3.80	83.2	253	.0185	1900	1280	.988
871			44.4	620	3.80	83.2	296	.0218	2110	1490	.993
846			16.9	620	1.44	82.8	58	.0112	1410	790	.961
847			16.9	620	1.44	82.8	75	.0145	1610	990	.951
848			16.9	620	1.44	82.8	93	.0179	1785	1165	.919
849			16.9	620	1.44	82.8	114	.0220	2010	1390	.915
850			16.9	620	1.44	82.8	132	.0255	2210	1590	.923
Combustion efficiencies - effect of temperature											
872			30.5	810	2.00	83.2	34	0.0047	1160	350	0.995
873			30.5	810	2.00	83.2	55	.0076	1360	550	.985
874			30.5	810	2.00	83.2	80	.0111	1560	750	.942
875			30.5	810	2.00	83.2	108	.0150	1810	1000	.954
876			30.5	810	2.00	83.2	134	.0186	2010	1200	.943
877			30.5	810	2.00	93.2	154	.0214	2160	1350	.937
823			30.5	440	3.70	85.6	140	.0105	1020	580	.724
824			30.5	435	3.70	82.6	181	.0136	1210	775	.760
825			30.5	430	3.70	81.7	225	.0168	1440	1010	.820
826			30.5	430	3.70	81.7	264	.0198	1660	1230	.862
827			30.5	430	3.70	81.7	295	.0222	1790	1360	.864
828			30.5	430	3.70	81.7	327	.0246	1940	1510	.879
Combustion efficiencies - effect of velocity											
859			30.5	620	4.20	134	146	0.0098	1235	615	0.857
860			30.5	620	4.20	134	200	.0132	1420	800	.828
861			30.5	620	4.20	134	252	.0166	1635	1015	.852
862			30.5	620	4.20	134	295	.0195	1780	1160	.845
863			30.5	620	4.20	134	324	-----	----	----	-----
864			30.5	620	4.20	134	310	.0205	1835	1215	.846
838			30.5	620	1.00	31.8	45	.0125	1510	890	.978
839			30.5	620	1.00	31.8	54	.0150	1685	1065	.991
840			30.5	620	1.00	31.8	66	.0183	1835	1215	.976
842			30.5	620	1.00	31.8	74	.0206	2010	1390	.971
843			30.5	620	1.00	31.8	83	.0231	2110	1490	.944

TABLE I - PERFORMANCE DATA FROM COMBUSTOR OPERATING WITH LIQUID MIL-F-5624 FUEL INJECTED BY SEVERAL DIFFERENT METHODS - Concluded

(f) Tube "C" injector

Point	Simulated engine speed (rpm)	Simulated altitude (ft)	Combustor-inlet static pressure (in. Hg)	Combustor-inlet temperature, °R	Air flow (lb/sec)	Combustor reference velocity (ft/sec)	Fuel flow (lb/hr)	Fuel-air ratio	Mean combustor-outlet temperature, °R	Mean temperature rise through combustor (°F)	Combustion efficiency
Altitude operational limits											
24	3000	40,000	7	450	0.6	60.5			No combustion		
23	3000	30,000	12	450	.9	52.9			No combustion		
22	3000	20,000	18	510	1.24	55.1	52	0.0116	1220	710	0.814
18	4000	40,000	12	470	.9	66.3			No combustion		
17	4000	30,000	15	495	1.37	70.9	48	.0097	1090	595	.806
12	5000	40,000	14	525	1.27	74.6	45	.0098	1080	555	.745
14	5000	50,000	8	525	.8	82.4			No combustion		
1	8000	50,000	18	680	1.34	79.3	97	.0201	1910	1230	.882
2	8000	60,000	11	710	.86	87.0	52	.0168	1610	900	.755
6	7000	60,000	9	650	.77	87.2			No combustion		
4	7000	50,000	15	660	1.22	84.1	66	.0150	1580	920	.852
8	6000	50,000	12	600	1.05	82.3	53	.0140	1560	960	.946
8	6000	50,000	12	600	1.05	82.3	41	.0108	1360	760	.948
9	6000	55,000	9	590	.85	87.4	41	.0134	1285	695	.703
10	6000	60,000	7	590	.65	85.9			No combustion		
Point			Combustion efficiencies - reference condition								
886			30.5	620	2.60	82.8	52	0.0056	1000	380	0.897
887			30.5	620	2.60	82.8	86	.0092	1185	565	.822
888			30.5	620	2.60	82.8	122	.0130	1410	790	.828
889			30.5	620	2.60	82.8	166	.0177	1680	1060	.840
890			30.5	620	2.60	82.8	207	.0221	1980	1360	.890
891			30.5	620	2.60	82.8	233	.0249	2160	1540	.910
Combustion efficiencies - effect of pressure											
907			44.4	620	3.78	82.8	77	0.0056	1000	380	0.881
908			44.4	620	3.78	82.8	123	.0090	1240	620	.921
909			44.4	620	3.78	82.8	176	.0129	1480	860	.913
910			44.4	620	3.78	82.8	227	.0167	1735	1115	.942
911			44.4	620	3.78	82.8	289	.0212	2000	1380	.940
902			16.9	620	1.44	82.8	39	.0075	1150	530	.938
903			16.9	620	1.44	82.8	58	.0112	1310	690	.834
904			16.9	620	1.44	82.8	77	.0148	1510	890	.828
905			16.9	620	1.44	82.8	98	.0189	1735	1115	.835
906			16.9	620	1.44	82.8	118	.0228	1960	1340	.852
Combustion efficiencies - effect of temperature											
912			30.5	800	2.00	82.2	62	0.0086	1390	590	0.941
913			30.5	810	2.00	83.2	81	.0112	1545	735	.912
914			30.5	810	2.00	83.2	105	.0146	1740	930	.909
915			30.5	805	2.00	82.7	135	.0188	1980	1175	.914
916			30.5	805	2.00	82.7	160	.0222	2160	1355	.906
892			30.5	435	3.72	83.0	102	.0076	845	410	.698
893			30.5	435	3.72	83.0	151	.0113	1030	595	.693
894			30.5	435	3.72	83.0	202	.0151	1260	825	.734
895			30.5	435	3.72	83.0	257	.0192	1550	1115	.801
896			30.5	435	3.72	83.0	306	.0228	1860	1425	.884
Combustion efficiencies - effect of velocity											
917			30.5	620	4.20	134	102	0.0067	1060	440	0.863
918			30.5	620	4.20	134	161	.0106	1240	620	.784
919			30.5	620	4.20	134	225	.0149	1485	865	.802
920			30.5	620	4.20	134	283	.0187	1660	1040	.782
921			30.5	620	4.20	134	344	.0227	1870	1250	.792
897			30.5	620	1.00	31.8	34	.0094	1260	640	.911
898			30.5	620	1.00	31.8	46	.0128	1510	890	.958
899			30.5	620	1.00	31.8	59	.0164	1660	1040	.889
900			30.5	620	1.00	31.8	76	.0211	1870	1250	.849
901			30.5	620	1.00	31.8	91	.0253	2060	1440	.834

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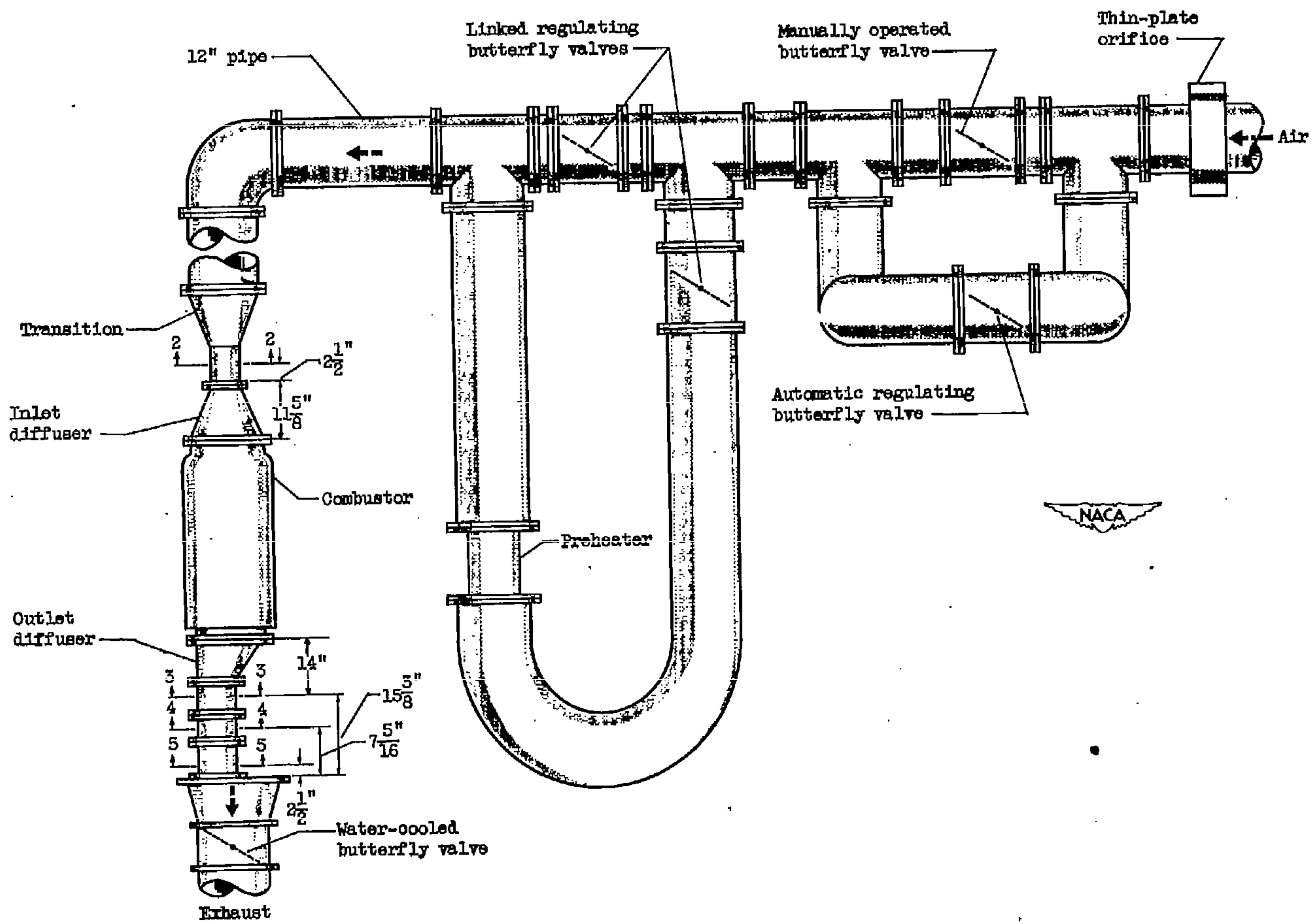

Figure 1. - Diagrammatic sketch of single-combustor setup.

[redacted]

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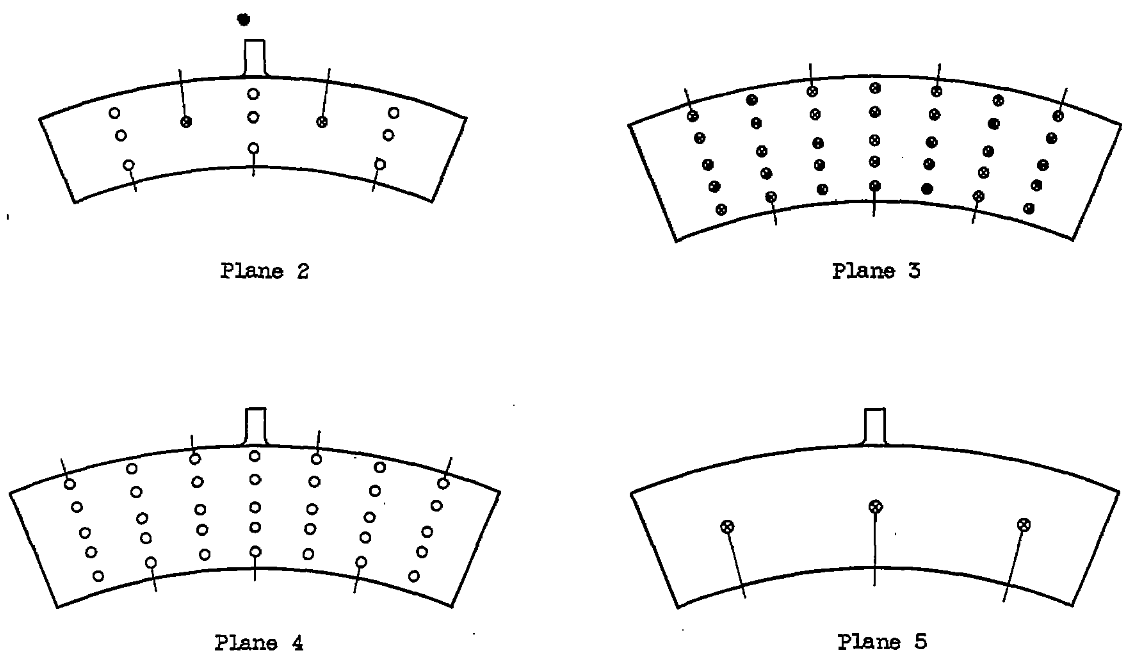

o Total-pressure tube

⊗ Thermocouple

⎍ Static-pressure orifice

Figure 2. - Stations of measurement at the instrumentation planes shown in figure 1.

20-1570

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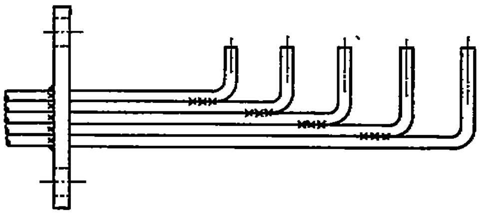
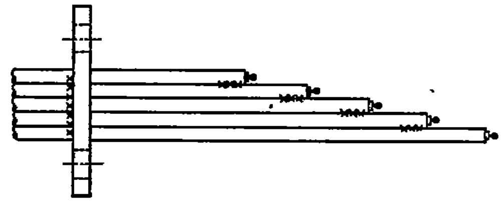
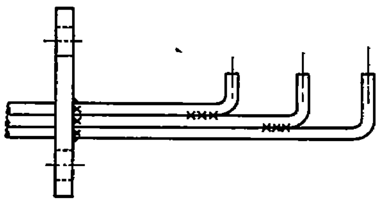


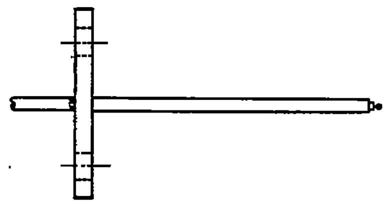
Five-tube total-pressure rake



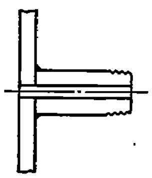
Five-thermocouple rake



Three-tube total-pressure rake



One-thermocouple rake



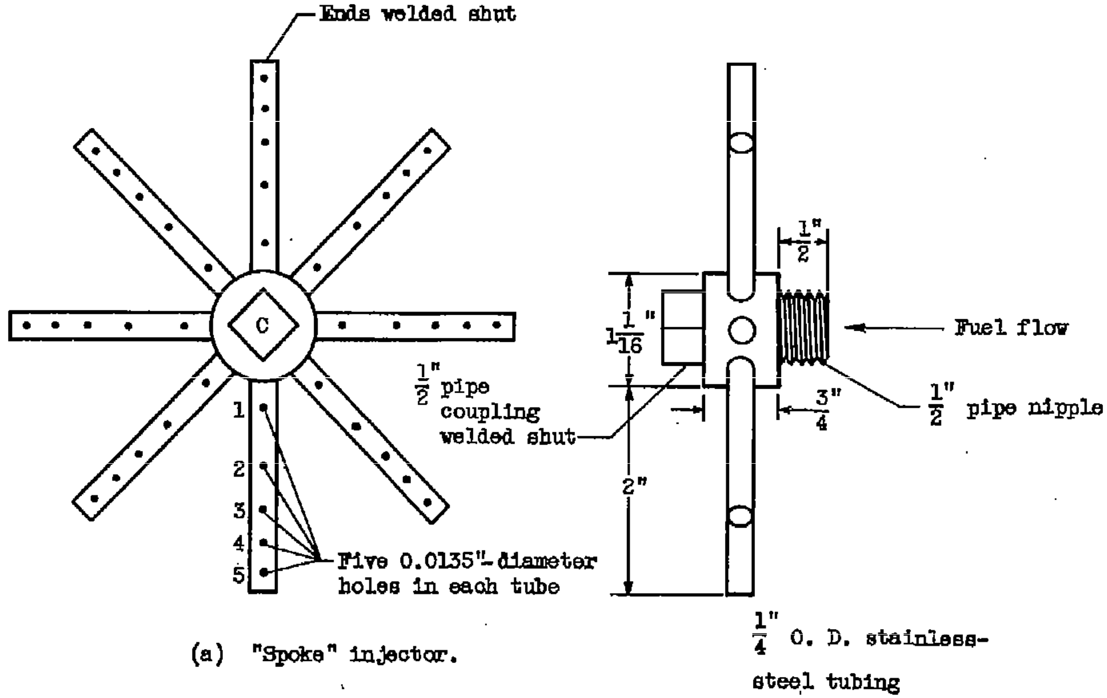
Static-pressure orifice connection

Figure 3. - Instrumentation details.

20-1969

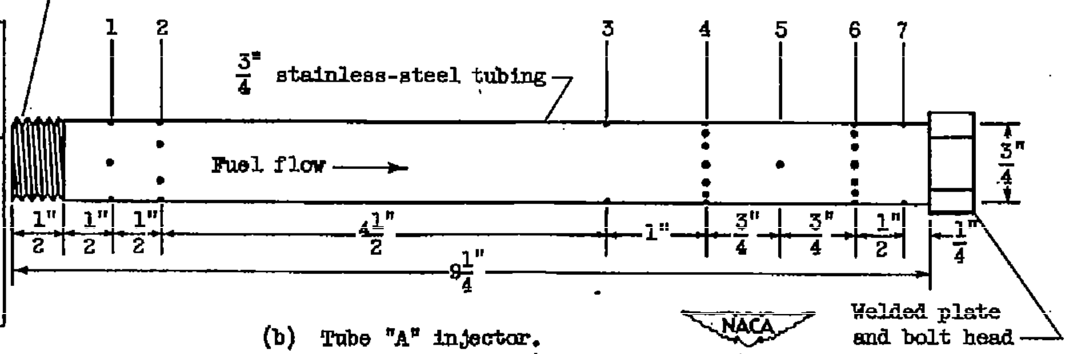
Radial distance from center of coupling C to each hole

	(in.)
1	$\frac{51}{64}$
2	$1\frac{3}{8}$
3	$1\frac{49}{64}$
4	$2\frac{3}{32}$
5	$2\frac{3}{8}$



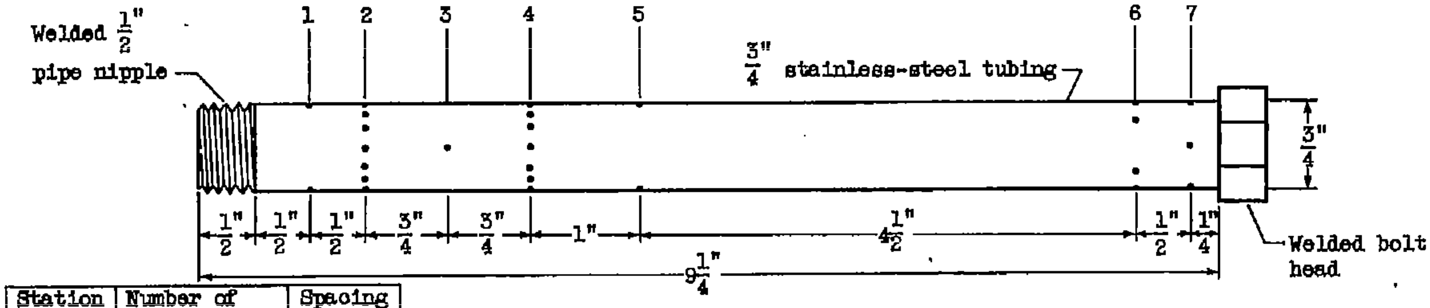
(a) "Spoke" injector.

Station	Number of 0.0135-inch-diameter holes	Spacing (deg)
1	4	90
2	6	60
3	2	180
4	12	30
5	2	180
6	12	30
7	2	180



(b) Tube "A" injector.

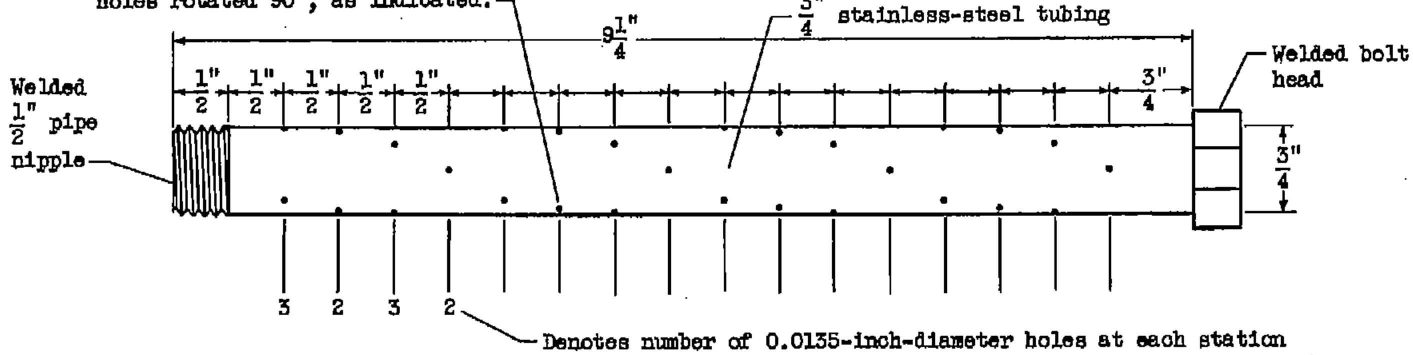
Figure 4. - Diagrammatic sketch of liquid MIL-F-5624 fuel injectors.



Station	Number of 0.0135-inch-diameter holes	Spacing (deg)
1	2	180
2	12	30
3	2	180
4	12	30
5	2	180
6	6	60
7	4	90

(c) Tube "B" injector.

Total of 40 0.0135-inch-diameter holes located at 16 stations evenly spaced at $\frac{1}{2}$-inch intervals along tube. Alternate stations have 2 and 3 holes, respectively, as indicated. Holes at each station evenly spaced circumferentially. Alternate 3-hole stations have holes rotated 180° and alternate 2-hole stations have holes rotated 90°, as indicated.



(d) Tube "C" injector.

Figure 4. - Concluded. Diagrammatic sketch of liquid MIL-F-5624 fuel injectors.

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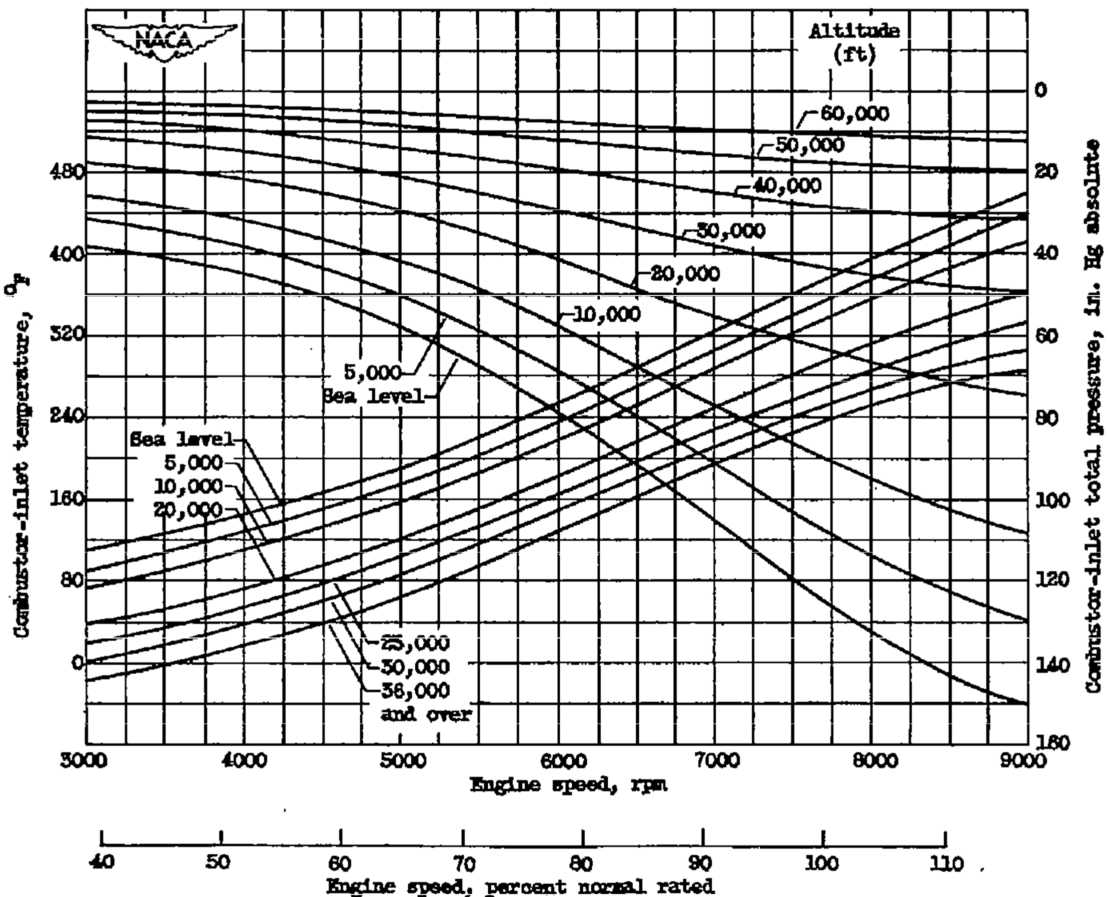
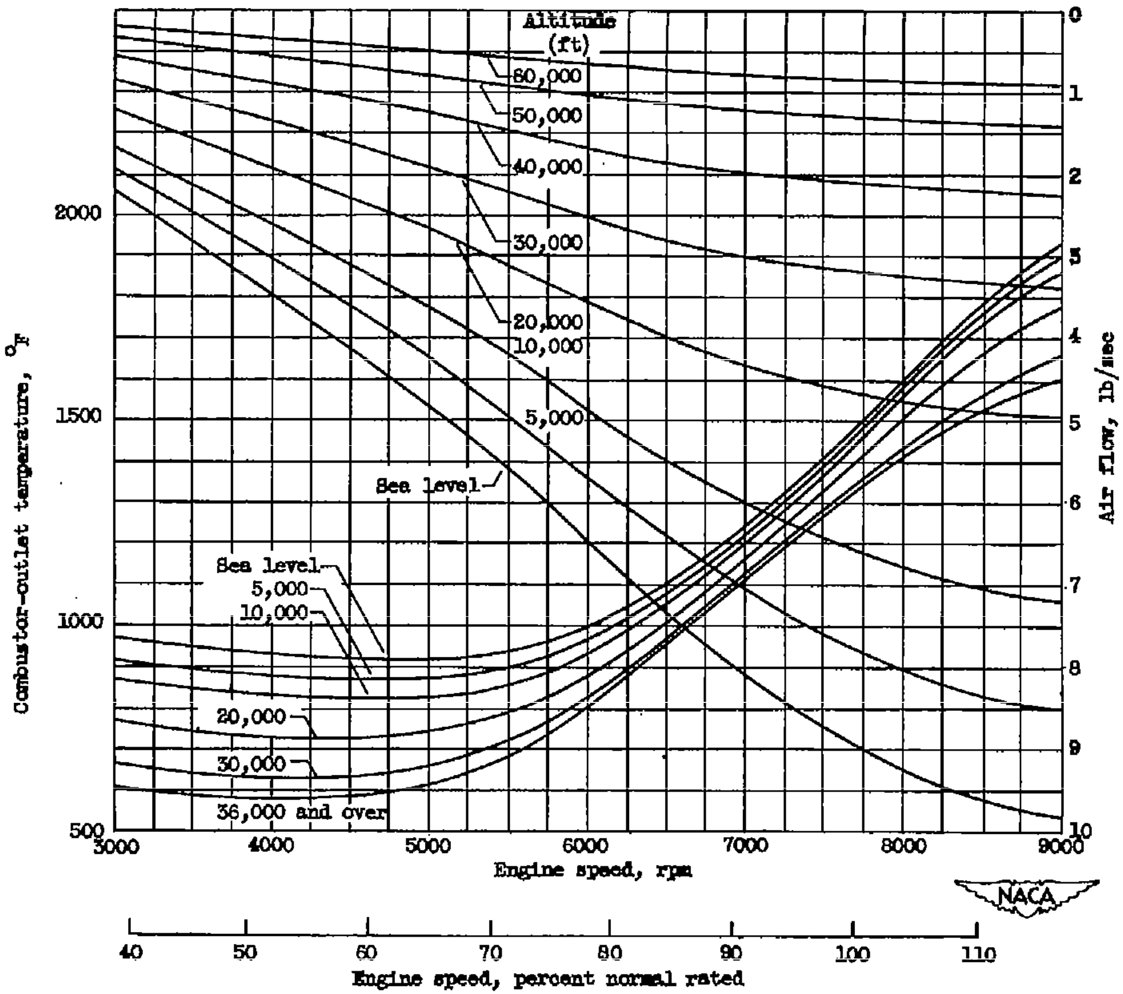


(a) Inlet temperature and pressure. Flight Mach number, 0.

Figure 5. - Control chart for single combustor investigated.

[redacted]

[redacted]



(b) Outlet temperature and air flow. Flight Mach number, 0.

Figure 5. - Concluded. Control chart for single combustor investigated.

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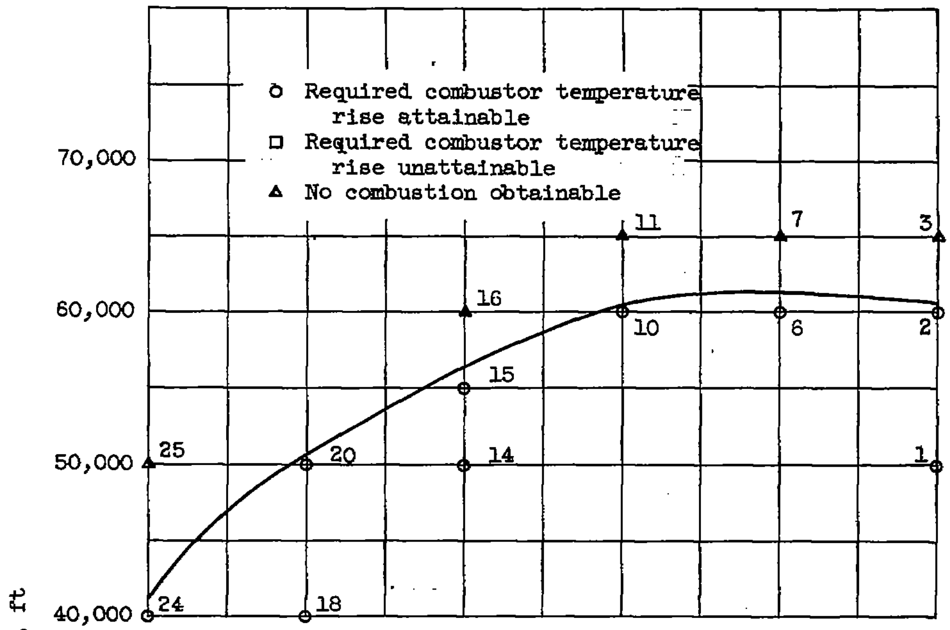
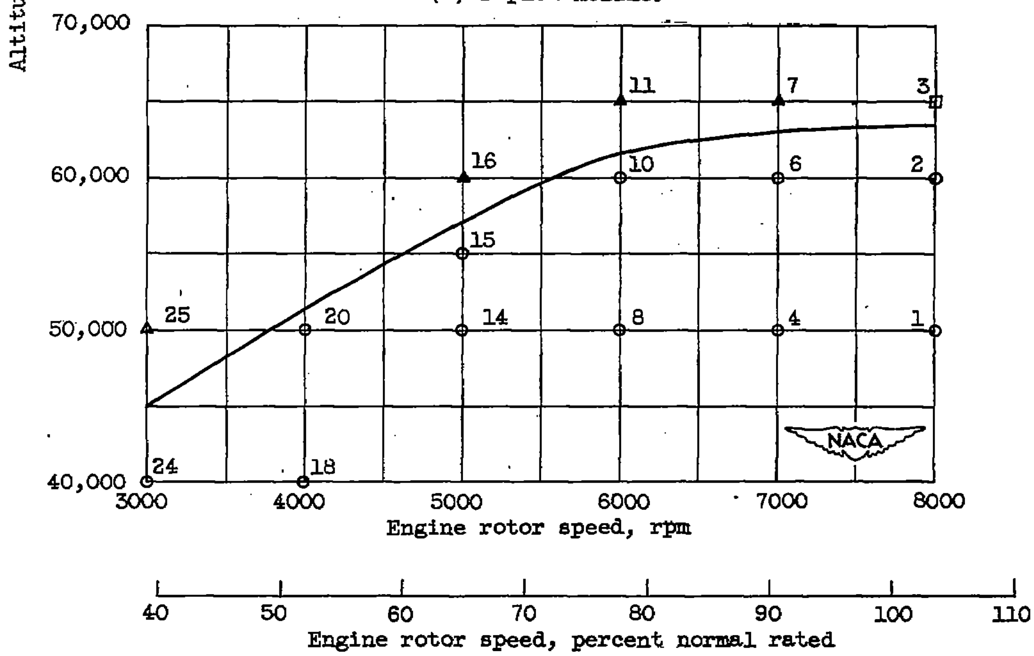


(a) Duplex nozzle.



(b) Simplex nozzle.

Figure 6. - Altitude operational limits and combustion efficiencies of single tubular combustor operating with liquid MIL-F-5624 fuel injected with six fuel-injector designs. Simulated flight Mach number, 0. (Point numbers listed in table I.)

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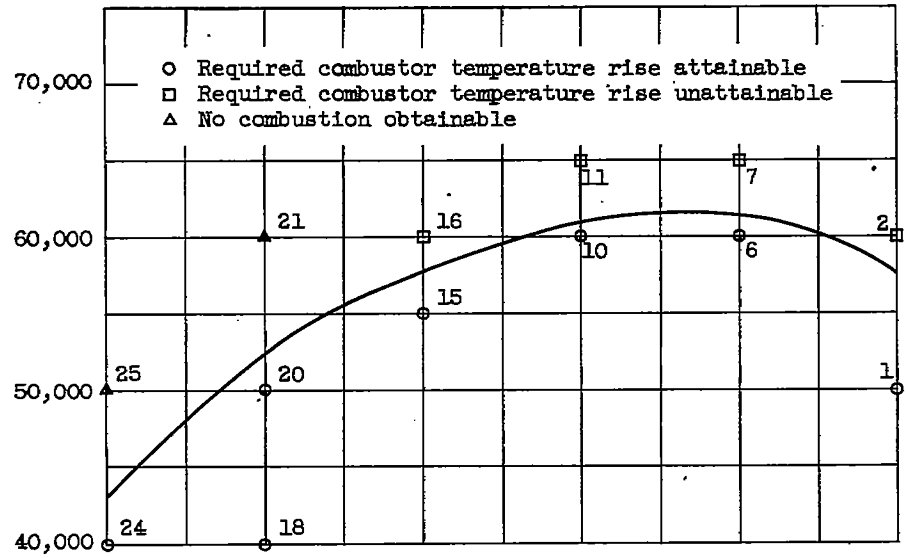
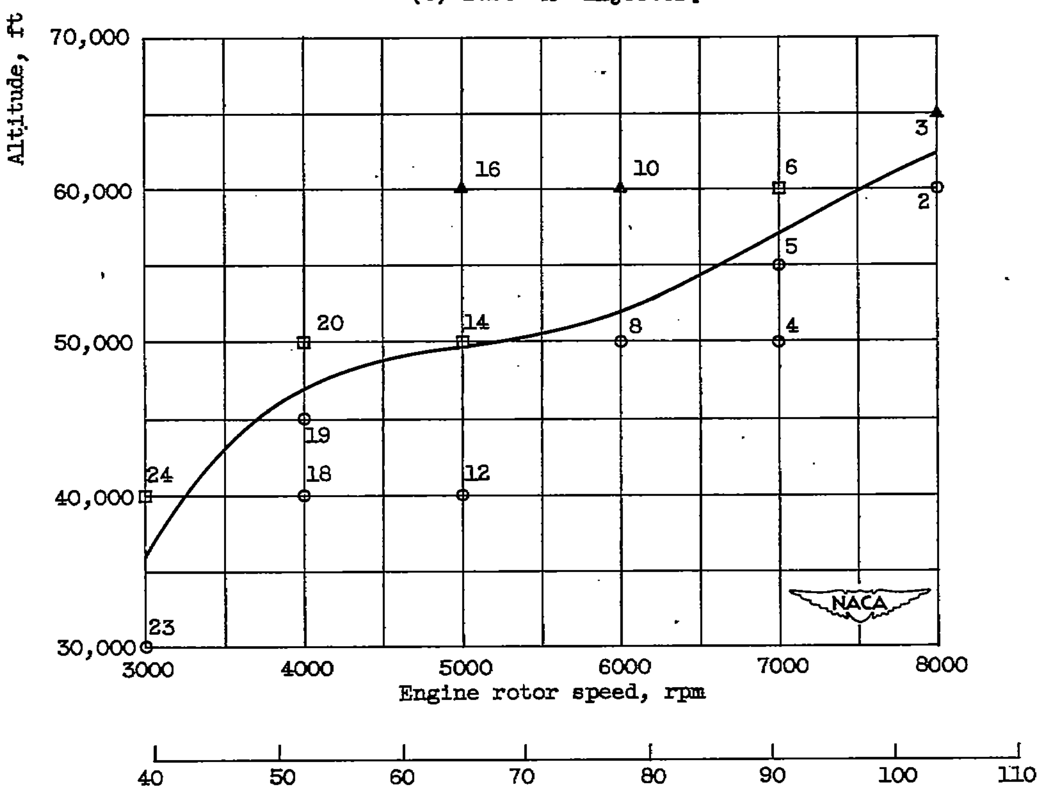


(c) Tube "A" injector.



(d) "Spoke" injector.

Figure 6. - Continued. Altitude operational limits and combustion efficiencies of single tubular combustor operating with liquid MIL-F-5624 fuel injected with six fuel-injector designs. Simulated flight Mach number, 0. (Point numbers listed in table I.)

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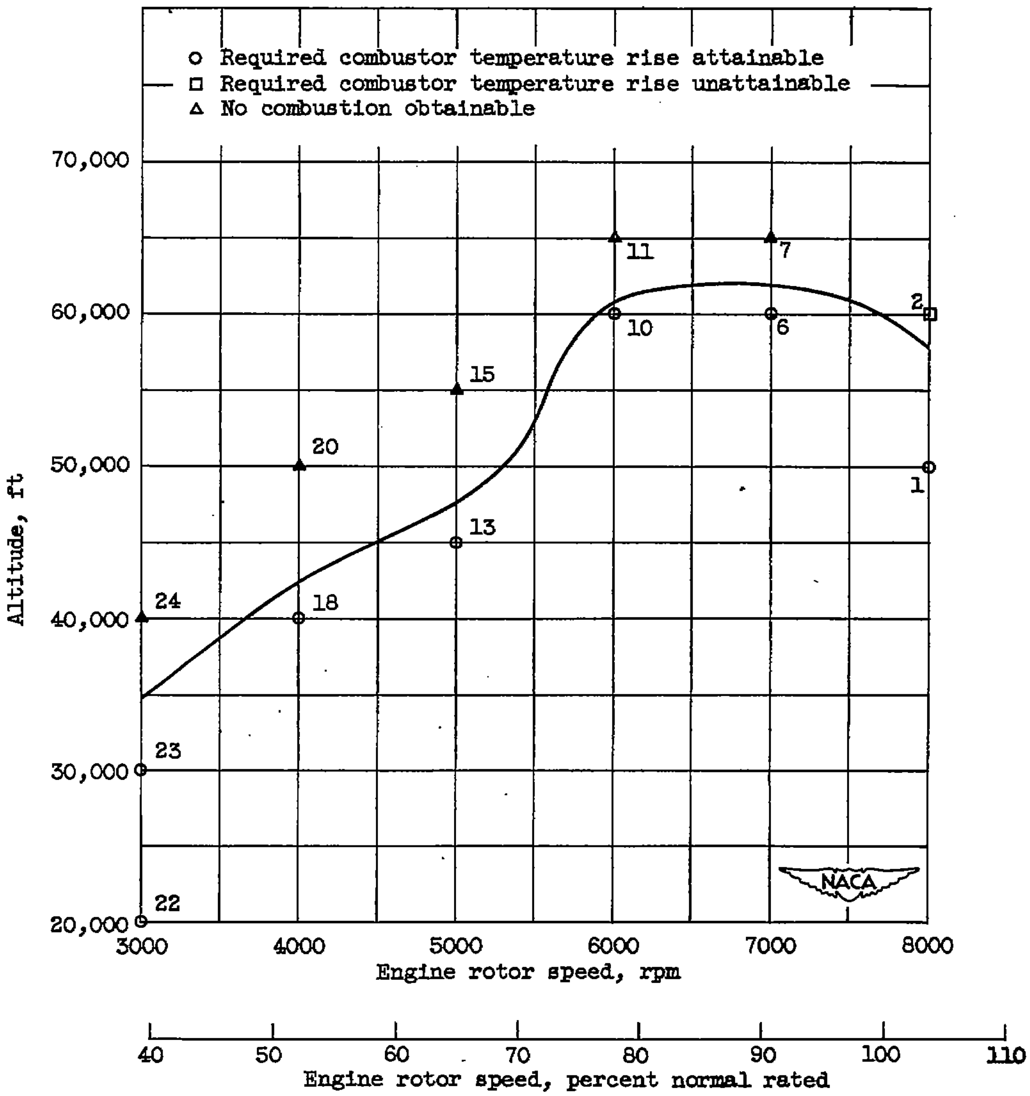

(e) Tube "B" injector.

Figure 6. - Continued. Altitude operational limits and combustion efficiencies of single tubular combustor operating with liquid MIL-F-5624 fuel injected with six fuel-injector designs. Simulated flight Mach number, 0. (Point numbers listed in table I.)

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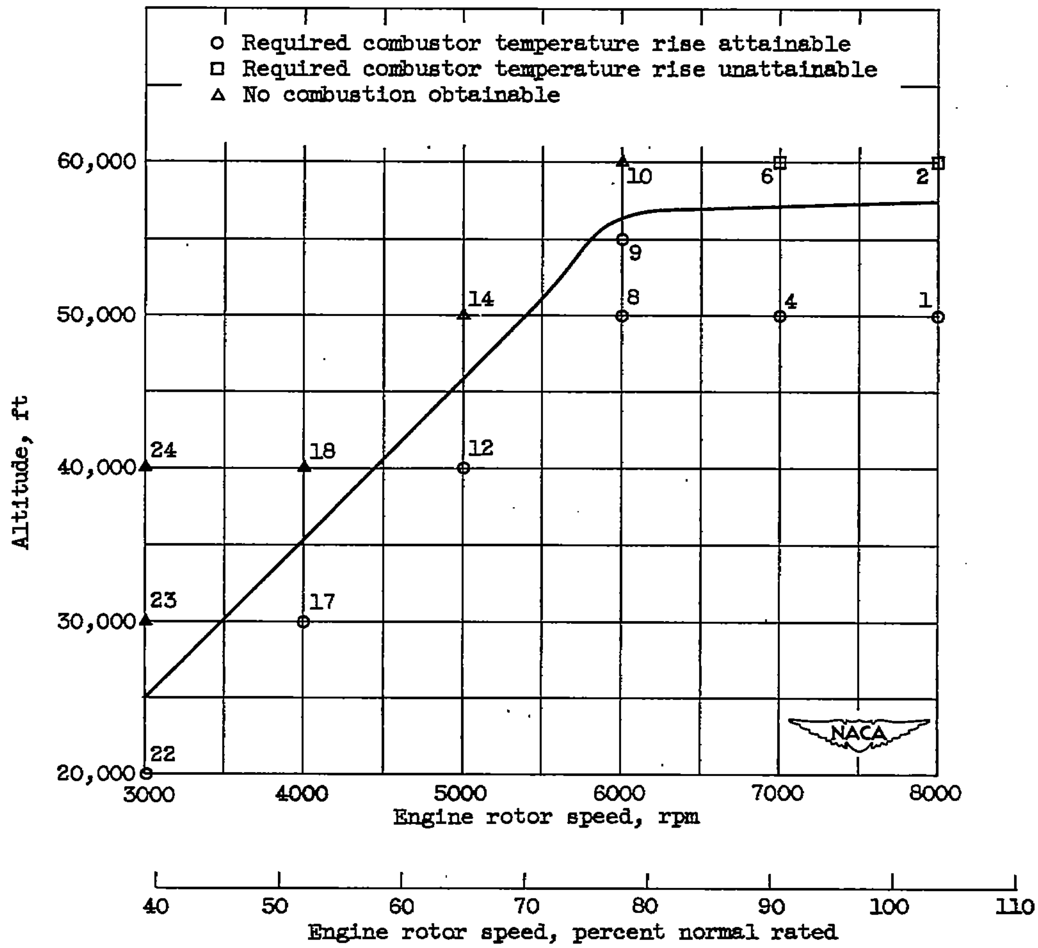

(f) Tube "C" injector.

Figure 6. - Concluded. Altitude operational limits and combustion efficiencies of single tubular combustor operating with liquid MIL-F-5624 fuel injected with six fuel-injector designs. Simulated flight Mach number, 0. (Point numbers listed in table I.)

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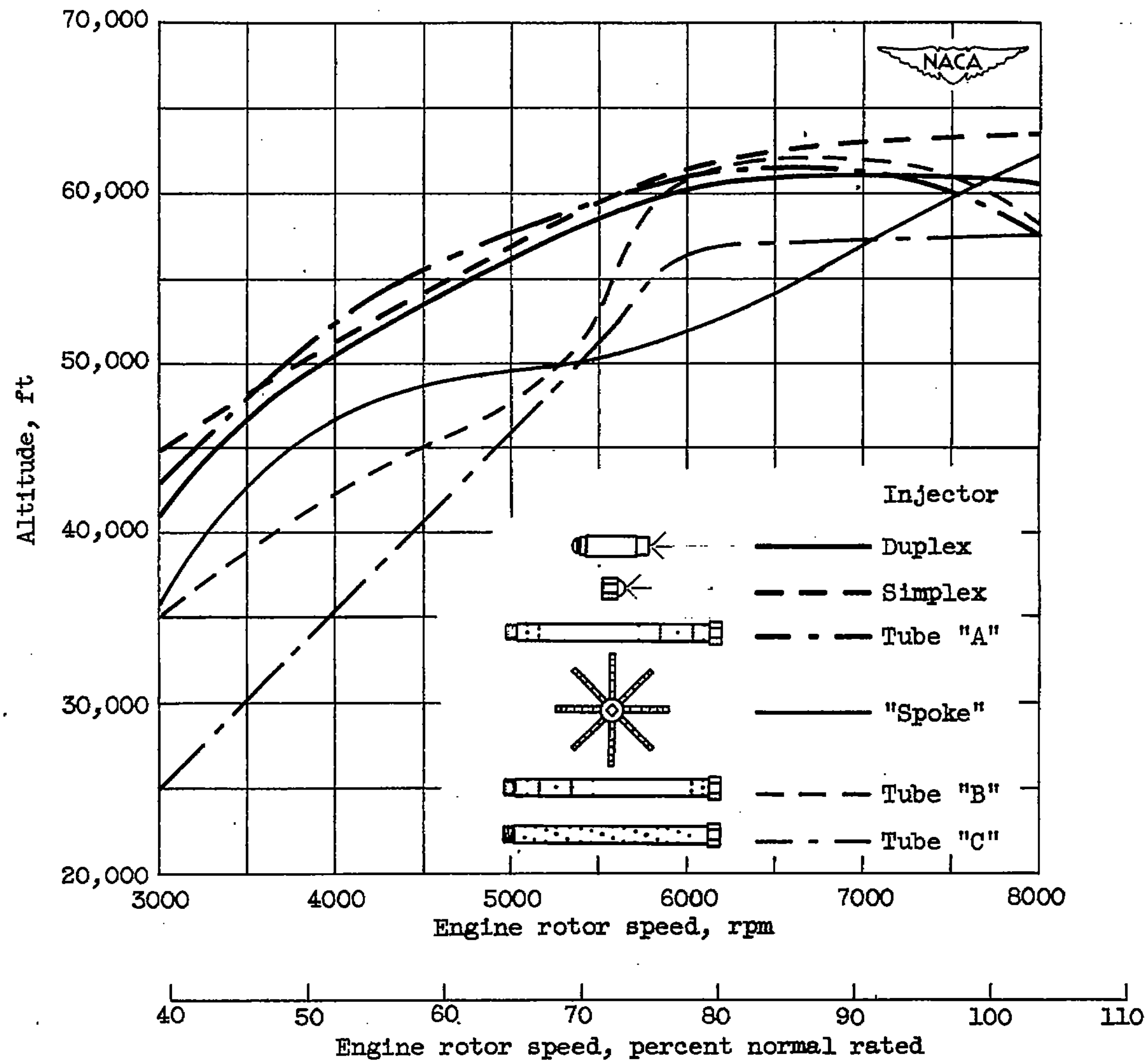

Figure 7. - Comparison of altitude operational limits of single tubular combustor operating with liquid MIL-F-5624 fuel injected by six different methods. Simulated flight Mach number, 0.

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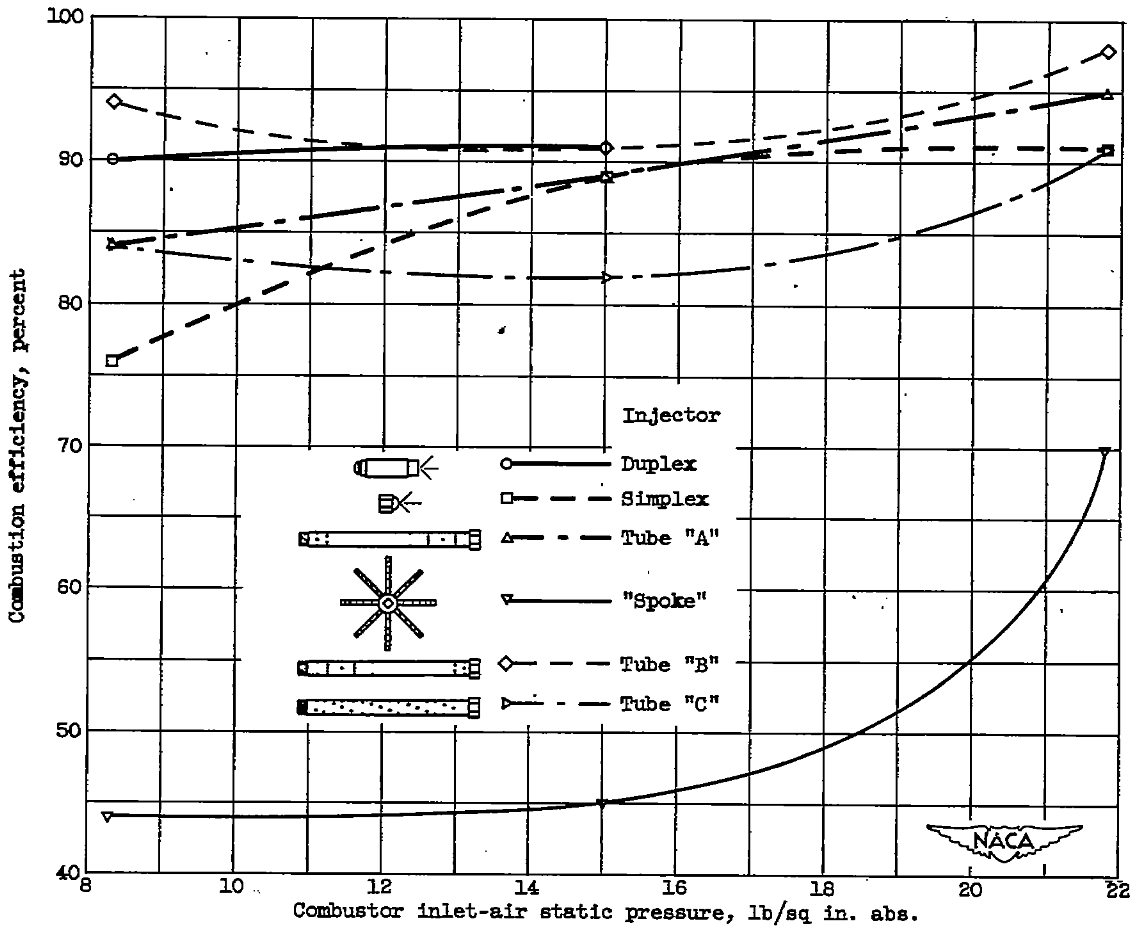

(a) Temperature rise, 650° F.

Figure 8. - Variation of combustion efficiency with inlet-air static pressure of tubular combustor operating with liquid MIL-F-5624 fuel injected by six different methods. Combustor conditions: temperature, 160° F; velocity, 80 feet per second.

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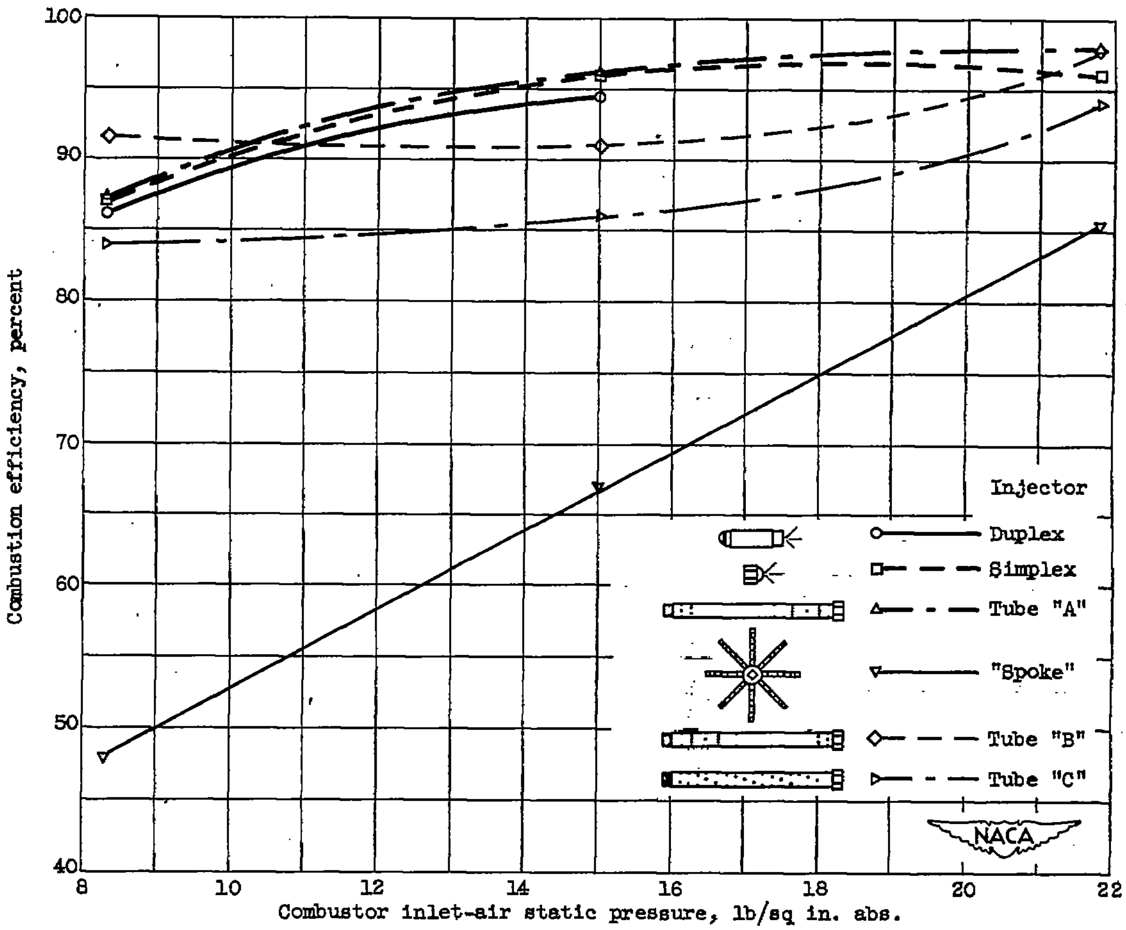

(b) Temperature rise, 1200° F.

Figure 8. - Concluded. Variation of combustion efficiency with inlet-air static pressure of tubular combustor operating with liquid MIL-F-5624 fuel injected by six different methods. Combustor conditions: temperature, 160° F; velocity, 80 feet per second.

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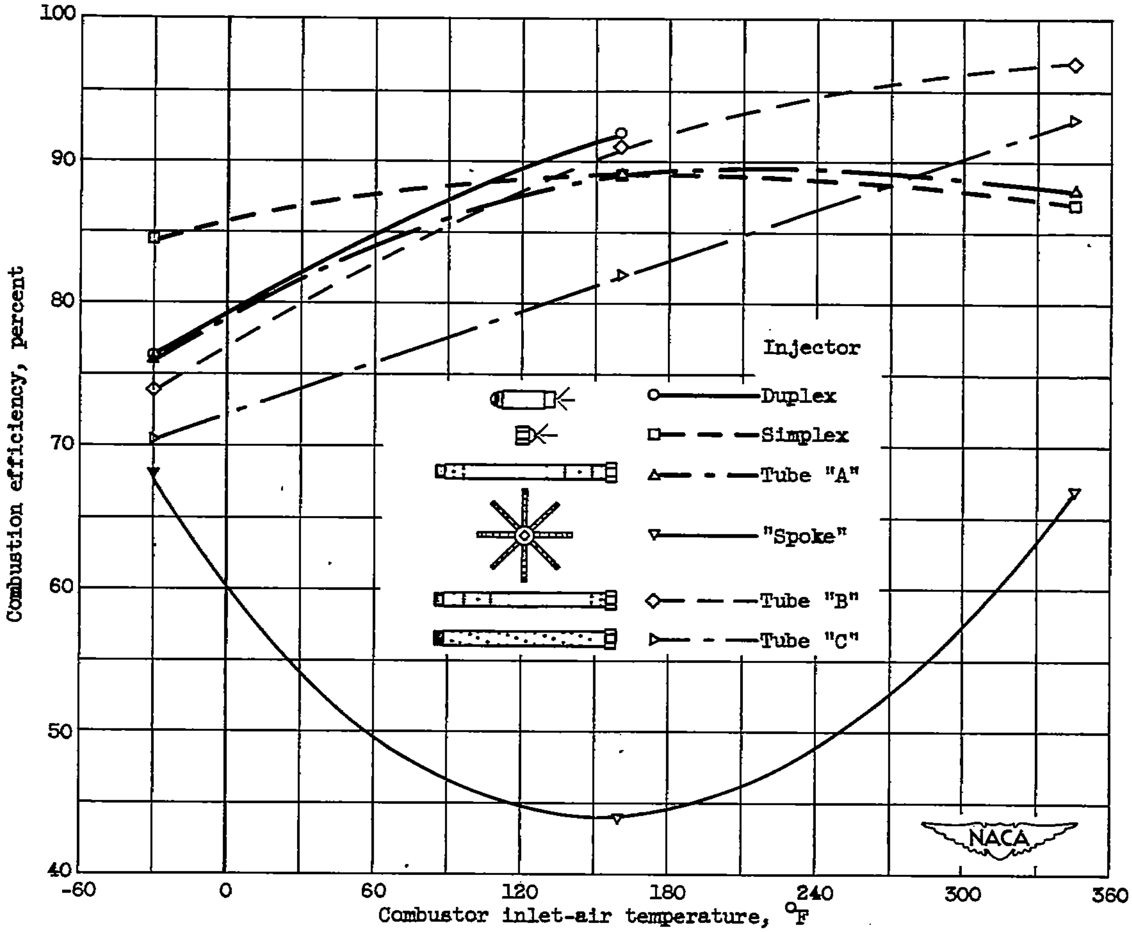
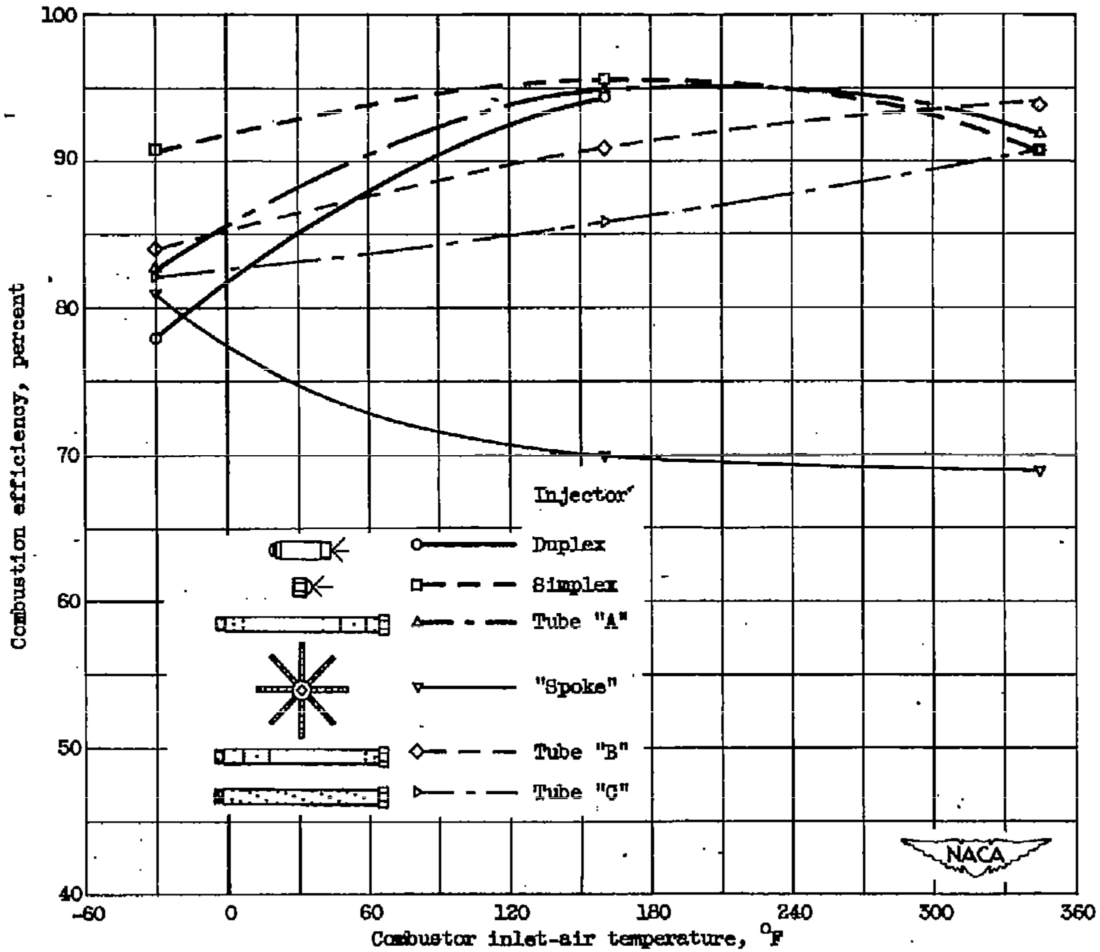


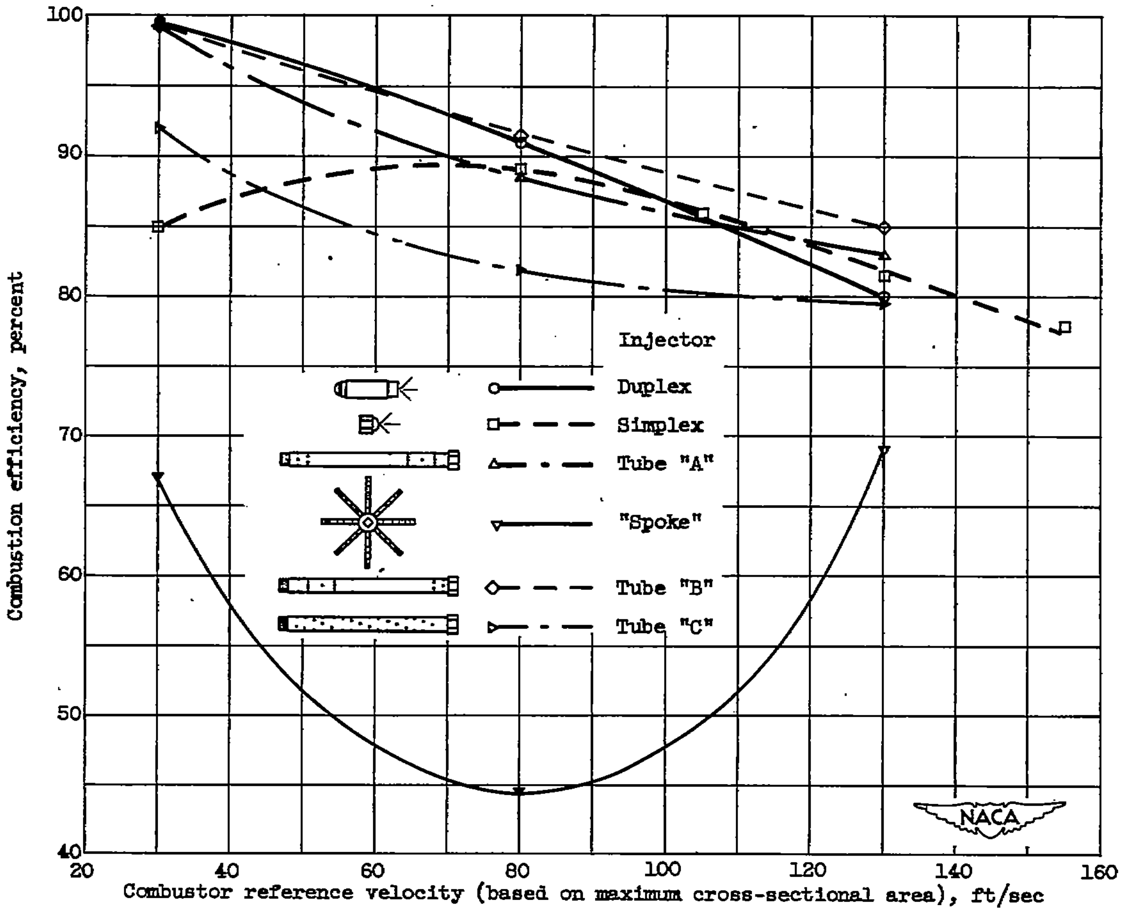
(a) Temperature rise, 650° F.

Figure 9. - Variation of combustion efficiency with inlet-air temperature of tubular combustor operating with liquid MIL-F-5624 fuel injected by six different methods. Combustor conditions: pressure, 15 pounds per square inch absolute; velocity, 80 feet per second.



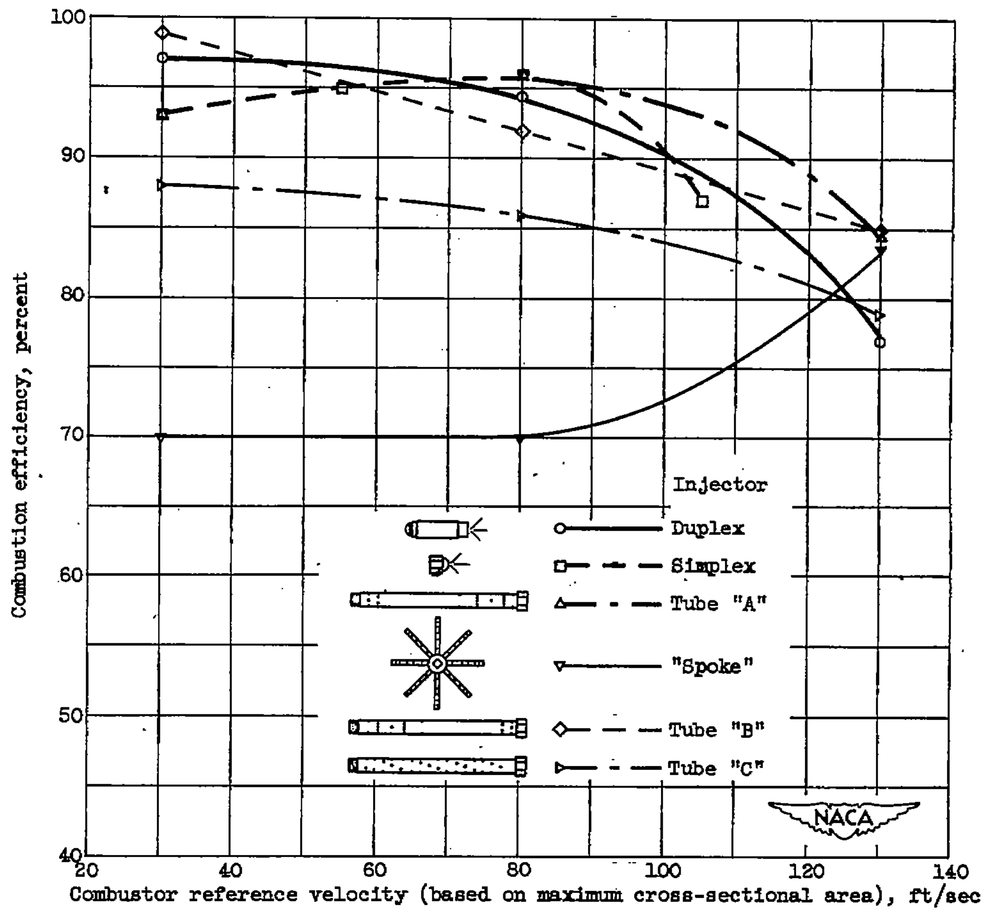
(b) Temperature rise, 1200° F.

Figure 9. - Concluded. Variation of combustion efficiency with inlet-air temperature of tubular combustor operating with liquid MIL-F-5624 fuel injected by six different methods. Combustor conditions: pressure, 15 pounds per square inch absolute; velocity, 80 feet per second.



(a) Temperature rise, 650° F.

Figure 10. - Variation of combustion efficiency with reference velocity of tubular combustor operating with liquid MIL-F-5624 fuel injected by six different methods. Combustor conditions: pressure, 15 pounds per square inch absolute; temperature, 160° F.



(b) Temperature rise, 1200° F.

Figure 10. - Concluded. Variation of combustion efficiency with reference velocity of tubular combustor operating with liquid MIL-F-5624 fuel injected by six different methods. Combustor conditions: pressure, 15 pounds per square inch absolute; temperature, 160° F.

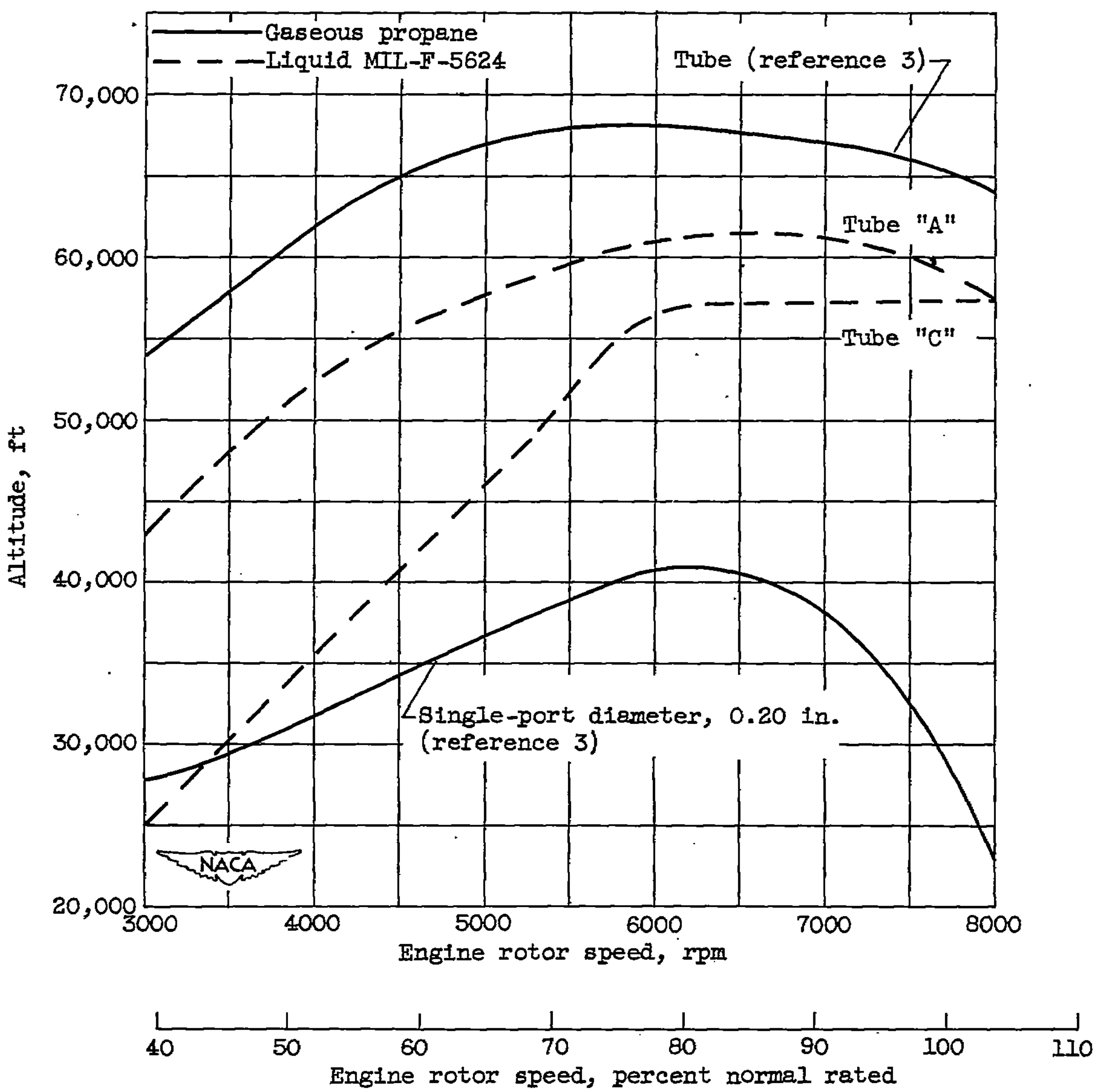
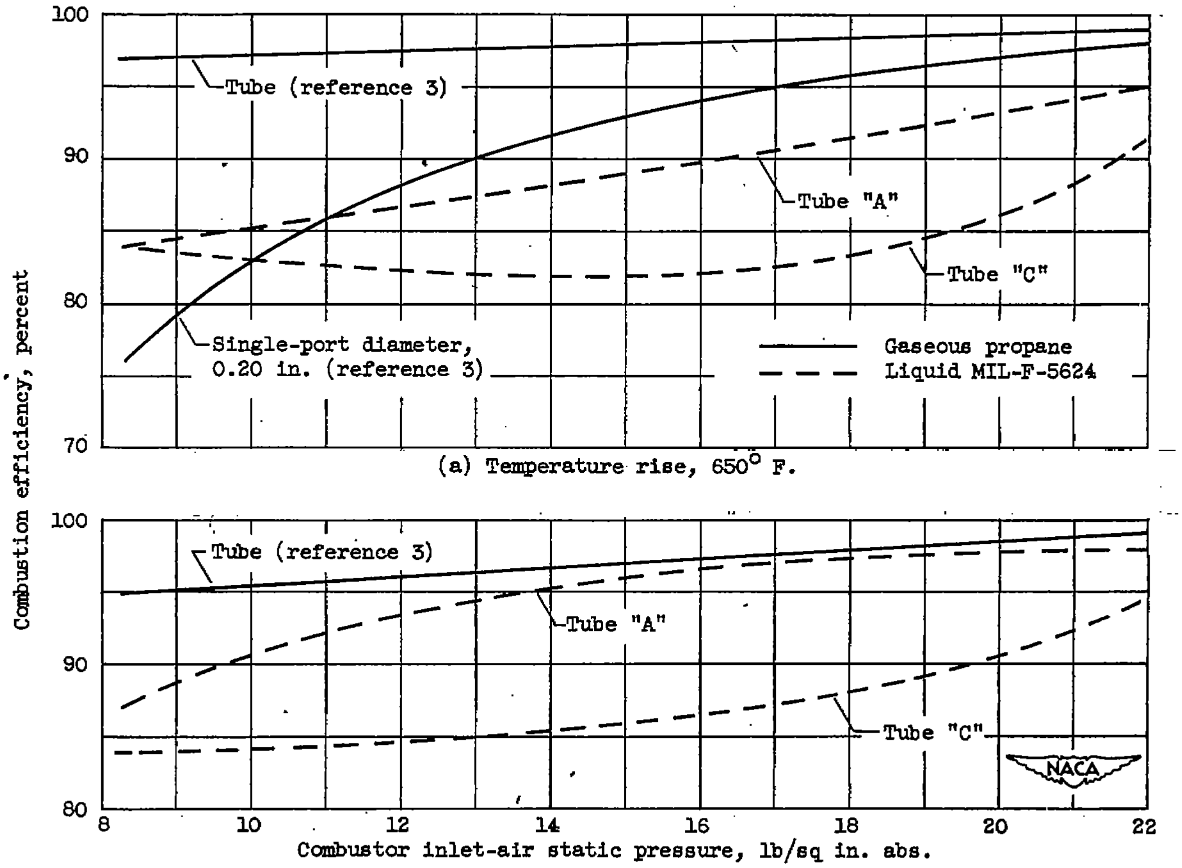


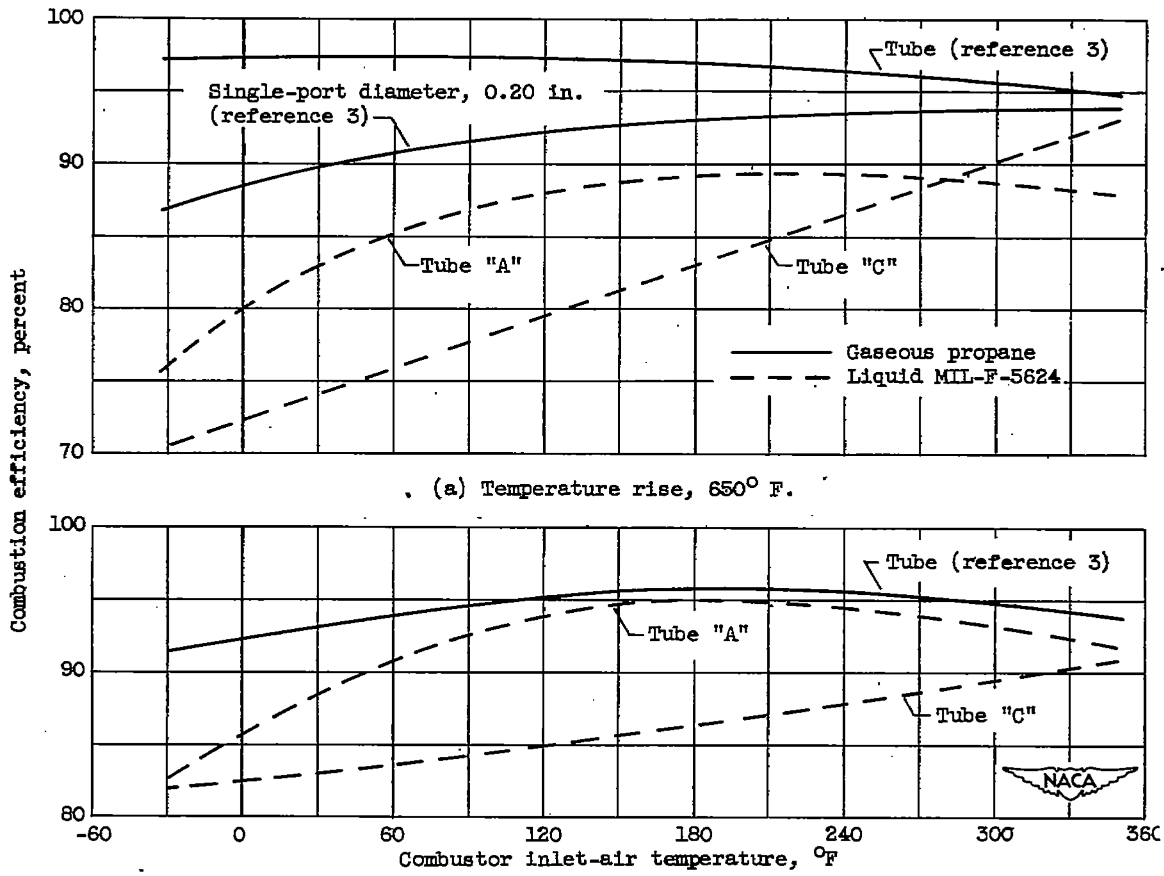
Figure 11. - Comparison of altitude operational limits of single tubular combustor operating with liquid and gaseous fuels. Simulated flight Mach number, 0.



(a) Temperature rise, 650° F.

(b) Temperature rise, 1200° F.

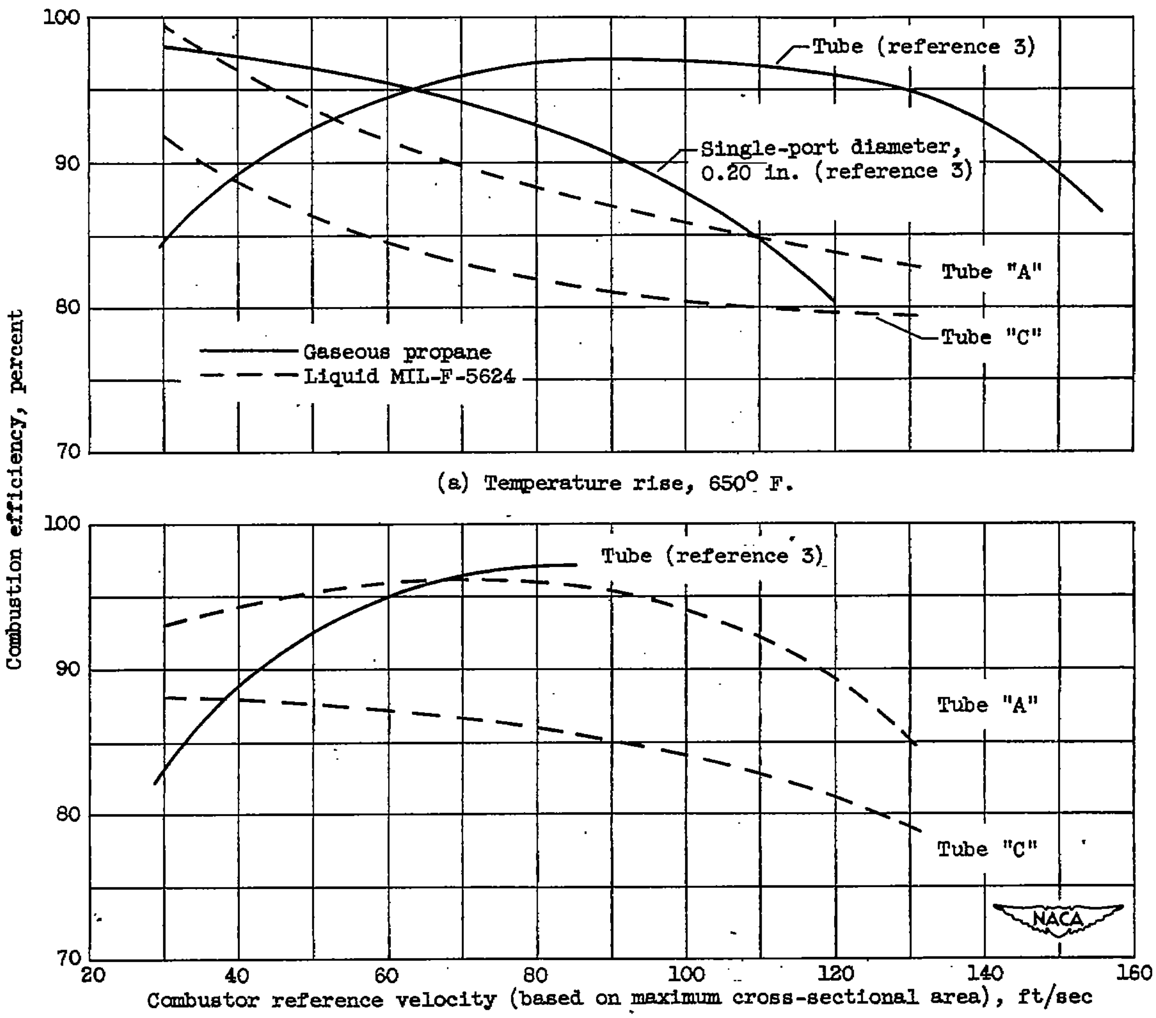
Figure 12. - Variation of combustion efficiency with inlet-air static pressure of tubular combustor operating with liquid MIL-F-5624 and gaseous propane fuels. Combustor conditions: temperature, 160° F; velocity, 80 feet per second.



(a) Temperature rise, 650° F.

(b) Temperature rise, 1200° F.

Figure 13. - Variation of combustion efficiency with inlet-air temperature of tubular combustor operating with liquid MIL-F-5624 and gaseous propane fuels. Combustor conditions: pressure, 15 pounds per square inch absolute; velocity, 80 feet per second.



(b) Temperature rise, 1200° F.

Figure 14. - Variation of combustion efficiency with reference velocity of tubular combustor operating with liquid MIL-F-5624 and gaseous propane fuels. Combustor conditions: pressure, 15 pounds per square inch absolute; temperature, 160° F.

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